Journal of Experimental Psychology

ARTHUR W. MELTON, Editor
HUMAN RESOURCES RESEARCH CENTER
LACKLAND AIR FORCE BASE
SAN ANTONIO, TEXAS

CONSULTING EDITORS

Judson S. Brown, *State University of Iowa*
Frank A. Geldard, *University of Virginia*
James J. Gibson, *Cornell University*
Clarence H. Graham, *Columbia University*
David A. Grant, *University of Wisconsin*
Lloyd G. Humphreys, *Human Resources Research Center*
Donald B. Lindsley, *University of California, Los Angeles*
Neal E. Miller, *Yale University*
Edwin B. Newman, *Harvard University*
Benton J. Underwood, *Northwestern University*
Delos D. Wickens, *Ohio State University*

Lorraine Bouthilet, Managing Editor

CONTENTS

The Effect of Stimulus Area and Intensity upon the Human Retinal Response: R. M. BOYNTON AND L. A. RIGGS 217

The Effect of a Change in Direction of Resultant Force on Sound Localization: The Audiogravic Illusion: A. GRAYBIEL AND J. I. NIVEN 227

The Generalization Gradient in Recognition Memory: L. POSTMAN 231

Drive Level and Reinforcement: J. DEESE AND J. A. CARPENTER 236

The Effect of Reinforcement on Closely Following S-R Connections: I. The Effect of a Backward Conditioning Procedure on the Extinction of Conditioned Avoidance: M. O. NAGATY 239

Latency and Duration of Monocular and Binocular After-Images: H. MISIAK AND C. C. LOZITO 247

Warm-up Effect as a Function of Level of Practice in Verbal Learning: L. E. THUNE 250

The Effect of Unequal Amounts of Practice on Motor Learning Before and After Rest: C. P. DUNCAN 257

Experimental Studies in Rote-Learning Theory: IX. Influence of Work-Decrement Factors on Verbal Learning: C. I. HOVLAND AND K. H. KURTZ 265

Response Variability in the White Rat During Conditioning, Extinction, and Reconditioning: J. J. ANTONITIS 273

American Psychological Association

Vol. 42 No. 4 October 1951

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

The JOURNAL OF EXPERIMENTAL PSYCHOLOGY is published monthly, two volumes per year, by the American Psychological Association, Inc. The subscription rate per volume is $7.00, or $14.00 annually. Single copies are $1.25. Subscriptions, orders, and business communications should be addressed to the American Psychological Association, Inc., Prince and Lemon Sts., Lancaster, Pa., or 1515 Massachusetts Avenue, N.W., Washington 5, D. C.

This JOURNAL publishes articles which are intended to contribute toward the development of psychology as an experimental science. Experimental work with normal human subjects is favored over work with abnormal or animal subjects. Studies in applied experimental psychology or engineering psychology may be accepted if they have broad implications for experimental psychology or for behavior theory. Normally, articles of a length exceeding 15 printed pages cannot be accepted. However, a single experimental study or an integrated series of studies accomplished simultaneously must be presented in a single article, rather than in a series of articles.

Articles are published in the order of their receipt, except in rare circumstances. Authors who request them are supplied with 50 free reprints without covers. However, under the new APA reprint policy no free reprints will be supplied to authors submitting manuscripts after January 1, 1952. All of the cost of the author's alterations in galley proof is charged to the author, and one-half of the cost of tables, cuts, and formulas.

Immediate publication can be given to articles whose authors assume the full cost of publication. Such articles must undergo the usual review by the Consulting Editors of the JOURNAL. No free reprints are given in the case of these articles.

Address all articles submitted for regular publication or for immediate publication to the editor, Arthur W. Melton, Human Resources Research Center, Lackland Air Force Base, San Antonio, Texas.

The JOURNAL adheres to the conventions concerning bibliographies, citations, preparation of tables and cuts, etc., as described by J. E. Anderson and W. L. Valentine, The preparation of articles for publication in the journals of the American Psychological Association, *Psychol. Bull.*, 1944, 41, 345–376. Special attention is called to the style of numbers and abbreviations (p. 353). The term 'experimenter,' with its various forms, singular, plural, and possessive singular and plural, is abbreviated *E*, *E*s, *E*'s, and *E*s'; analogous abbreviations are used for the terms 'subject' (*S*) and 'observer' (*O*). All manuscripts must be typed double-spaced throughout, including tables, footnotes, references, and titles for figures. Tables, figures, footnotes, references, and titles for figures must be placed on separate pages at the end of the manuscript.

Entered as second-class matter, February 6, 1937, at the post office at Lancaster, Pa., under the Act of March 3, 1879.

Acceptance for mailing at the special rate of postage provided for in paragraph (d-2), Section 34.40, P. L. & R. of 1948, authorized September 11, 1947.

Journal of
Experimental Psychology

VOL. 42 NO. 4 OCTOBER 1951

THE EFFECT OF STIMULUS AREA AND INTENSITY UPON THE HUMAN RETINAL RESPONSE

BY ROBERT M. BOYNTON AND LORRIN A. RIGGS

Brown University[1]

A classical problem in vision is that of the relationship between stimulus area and the intensity of light necessary to produce a given effect. For the most part, the problem has taken the form of finding the particular combinations of area and intensity for which a stimulus flash is just visible to the subject.[2] The most recent of these studies have shown that earlier empirical formulations of the data ($IA = C$; $I\sqrt{A} = C$; $IA^k = C$) are of only limited value. Graham and his co-workers, basing their analysis upon physiological considerations of spatial summation,[3] have developed a more specific quantitative expression for area-intensity relationships at threshold.

While there is little doubt that spatial summation in the human retina accounts in large measure for area-intensity relationships at threshold, the situation may be very different at higher levels of excitation. Inhibitory effects may well occur, and certainly the scattering and reflection of light within the eyeball become factors of increasing importance as the intensity of stimulation is raised (**5**). Relatively high intensities of flash have been used in the flicker experiments of Granit and Harper (**9**), and in the experiments of Page (**18**), in which a pupillary response was observed. It is perhaps significant that in both of these studies a nearly

[1] These experiments were performed in connection with Project NR-140-359 under Contract N7onr-358, Task Order II, between the Office of Naval Research and Brown University.

[2] Noteworthy among these investigations are those of Ricco (**22**), Piper (**20**), Piéron (**19**), Graham and Margaria (**8**), Karn (**15**), Wald (**27**), Graham, Brown, and Mote (**7**), and Brown and Niven (**3**).

[3] Adrian and Matthews (**1**) called attention to the facilitating effects of one region upon adjacent ones in the retina of the eel, accounting for their results on the basis of lateral interconnecting neurones. Graham (**6**) demonstrated that such interaction was not found in Limulus, whose eye appears to be lacking in lateral connections. Hartline (**12**) provided the most direct evidence of neural interaction in his experiments on the "receptive field," corresponding to a single nerve fiber in the frog. He found that (a) a given optic nerve fiber responds to stimulation by light throughout a small area of the retina (the "receptive field"), (b) the receptive field is maximally sensitive at a center, and requires progressively more illumination to elicit a nerve discharge by stimulation of points farther and farther from this center, (c) these areas were slightly less than 1 mm. in diameter, and somewhat irregular in shape, and (d) the area and intensity of the exploring spot were interchangeable, within limits, for the arousal of a given magnitude of response in the nerve fiber.

reciprocal relationship between area and intensity is seen over a wide range of response magnitudes.

The present experiments are mainly concerned with area-intensity relationships in the arousal of electroretinograms in the human eye. Incidental observations of these effects have been reported by Sachs (**26**), Hartline (**11**), Cooper, Creed and Granit (**4**) and Monnier (**17**). No systematic study was practical, however, until the development of a technique for continuous recording, over periods of several hours, of the human electroretinograms in response to flashes of light (**23**). The present electrical experiments are similar to those of Page (**18**), who used pupillary constriction as a response measure, in that high stimulus intensities were necessarily employed to arouse the physiological effect being studied, and sets of data were found relating the magnitudes of the effect to specific values of area and intensity.

Apparatus

The apparatus was so closely patterned after that used by Johnson (**14**) that a detailed description is unnecessary. The essential features are shown in Fig. 1, which is largely self-explanatory. As mentioned previously, the element which makes recording from human *Ss* possible is a corneal electrode, mounted in a contact lens as described by Riggs (**23**). The *S*'s eye, properly aligned by the use of a biting board and fixation points, is stimulated by .04-sec. flashes of white light, supplied from the stimulus lamp (*SL*), with the exposure determined by a gravity type slotted disc shutter (*Sh*). The potential difference between the two electrodes E_f and E_e was recorded by means of a direct-coupled amplifier and an oscillographic recording system.

The following important modifications of the apparatus described by Riggs and Johnson were made:

Light source.—In order to provide a uniform retinal stimulation it is best to use a light source with a finite area of uniform intensity. Such a lamp was available in the Cenco No. 12334

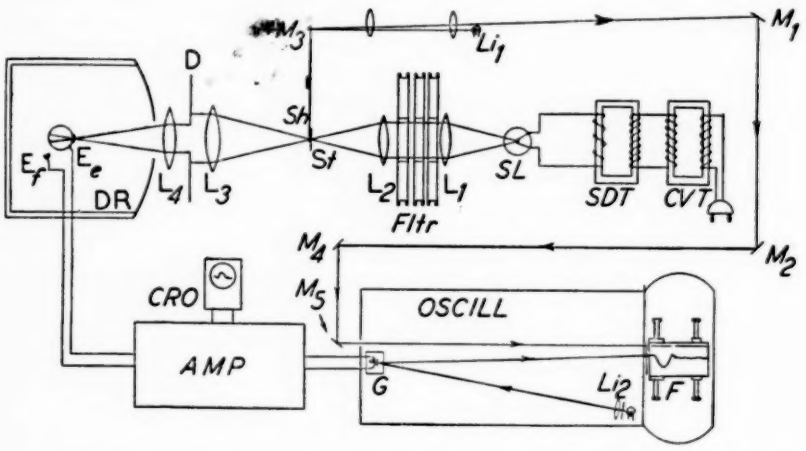

Fig. 1. Diagram of the apparatus. *AMP*—direct coupled amplifier; *CRO*—cathode ray oscillograph; *CVT*—constant voltage transformer; *D*—variable diaphragm; *DR*—electrically shielded dark room; E_e—corneal electrode supported by contact lens; E_f—forehead electrode; *F*—film, driven at a constant rate; *Fltr*—Wratten neutral-density filters; *G*—loop galvanometer; L_1, L_2—first pair of collimating lenses; L_3, L_4—second pair of collimating lenses; Li_1—source for signal system; M_1 to M_5—mirrors for signal system; *OSCILL*—oscillograph unit; *SDT*—step-down transformer; *Sh*—pendulum-type shutter; *SL*—stimulus lamp, ribbon filament; *St*—stop, aperture 1 mm. in diameter.

tungsten ribbon filament laboratory bulb (*SL*). The lamp used throughout the experiments was operated at its rated voltage of 3.81 v., drawing a current of approximately 77.5 am., operating at a rated temperature of 3250° K. Because of the very large current required to operate this lamp, the use of a direct current source was deemed impracticable, and the 110-v. supply was used, together with a step-down transformer (*SDT* in Fig. 1) and, as an added precaution, a constant voltage transformer (*CVT*).

Optical system.—A variable diaphragm *D* was interposed between lenses L_3 and L_4, partially intercepting the rays as shown. The stimulus appeared to *S* as a "Maxwellian view" of a uniform field in the plane of L_4, the size of which was defined by the opening of the diaphragm *D*.

Position of S's eye.—A biting board was used to maintain a constant position of the head. Further control of the eye position was obtained with the use of suitable fixation points. A sheet of clear glass, when properly adjusted, partially reflected the light from any one of a number of moveable "grain of wheat" lamps. By means of a multiple selector switch, these lamps could be activated one at a time, thereby varying the eccentricity of fixation with respect to the center of the stimulus patch. For central fixation, *S* was able to make the biting board adjustment without help. For peripheral fixation, however, it was found that *E* was required to make the final adjustment, using a mirror to insure that the entire pencil of rays was entering the pupil.

Calibration of the stimulus.—The results of photometric matches and calculations indicated that the retinal illumination under the experimental conditions with no filters in the system was of the order of two million foot-lamberts.

Amplifier.—As in the experiments of Riggs and Johnson (**24**), the amplifier was of a direct-coupled type, insuring a faithful reproduction of even a rectangular-wave input.

Signal device.—A metal projection of the same arc as the slit which passed the stimulus was mounted on the shutter. This projection served to interrupt a beam of light from Li_1 (see Fig. 1) which was focused through lenses as shown and reflected from a small mirror (M_3) by way of mirrors M_1 to M_2 onto the recording film (*F*) in the oscillograph (*OSCILL*). By means of this device, the duration of the stimulus was indicated on the record as a break in an otherwise continuous line. This signal was calibrated to insure that it was properly synchronized with the duration of the stimulus flash.

Oscillographic recording system.—The output from the amplifier was fed to a loop galvanometer (*G*) containing a small mirror. This galvanometer was part of the oscillograph unit, a Hathaway Oscillograph, Type S-14-A. Potential changes in the amplifier were followed, with negligible damping effect, by a proportional rotation of the galvanometer mirror. Light from a lamp Li_2 was focused by a lens, and reflected from the galvanometer mirror onto the film (*F*). The film was driven at a constant rate and thus, when processed, provided a permanent record of the changes in electrical potential between the two electrodes on the *S*.

TABLE I

SUMMARY OF STIMULUS AREAS USED

Visual Angle of Stimulus in Deg.	Calculated Retinal Area in Mm.²	Log Retinal Area	Diaphragm Opening in Mm.
1.25	.11	$\bar{1}.04$	3.8
2.0	.28	$\bar{1}.45$	6.0
2.5	.44	$\bar{1}.64$	7.5
3.0	.64	$\bar{1}.81$	9.0
4.0	1.13	0.05	12.0
6.0	2.54	0.40	18.0
8.0	4.52	0.66	24.0
10.0	7.08	0.85	30.0
12.0	10.20	1.01	36.0

PROCEDURE

Main experiment.—The data of the main experiment were obtained from three normal *S*s and were secured in a total of 12 experimental sessions, four for each *S*. The breakdown of these four sessions was twofold: (a) in terms of the two main experimental conditions (central and 30° peripheral fixation), and (b) in terms of the range of intensities used. The first of the two experiments for each of these main conditions was conducted as follows: For each of the areas used (See Table I for a summary of areas) a range of intensities was employed ranging from the weakest which would produce a measurable response to the greatest which could be used safely and conveniently. A total of from 50 to 125 stimuli were given in a single experimental session with *S* in a dark-adapted state (45 min. in the dark before each experiment began). Sufficient time was allowed between stimuli to permit the eye to recover from the previous short flash. Empirical check established this period as between 30 and 90 sec., depending upon the magnitude of the previous flash. The usual experimental session lasted from 2 to 3 hr., including dark-adaptation, depending on the range of stimuli used and the state of *S*'s eye. The range of intensities employed in these initial sessions was such that a plot of *B-wave* height as a function of stimulus intensity usually included

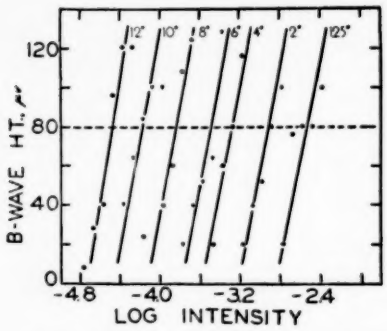

FIG. 2. Results from typical experiment where stimuli were massed around the value which was calculated to produce a criterion *B-wave* response of 80 microvolts. A horizontal line drawn through the 80-microvolt value intersects each line at the intensity value required to elicit a criterion response for that area. Intensity is given in logarithmic units below a reference of 0.0, the retinal brightness for which is approximately 2×10^4 foot-lamberts.

the entire straight rise of the total ogival function and a portion of the ends.

A second pair of sessions for each *S* was devoted to the exact determination, for the peripheral and central conditions, of the intensity required at each area to produce a criterion *B-wave* response of 80 microvolts.[4] This procedure involved the determination of only a small portion of the lower straight-line portion of the ogival function described above. Using the *CRO* as a monitoring device, together with the information available concerning the entire function, approximately six stimuli, separated in intensity by only .1 log unit, were given, concentrated around the value calculated to produce approximately the criterion response of 80 microvolts. Intensity was varied by means of Wratten neutral-density filters (*Fltr* in Fig. 1).

RESULTS

Figure 2 illustrates the results from a typical experiment where the stimuli were massed as described above. This plot of *B-wave* height as a function of log intensity may be considered a straight line for the short length involved. In order to determine the intensity-area combinations required to produce a criterion response, it is necessary to intersect each of these functions with a horizontal line which cuts the *y*-axis at the criterion value. After these values have been determined (intensity for each area) from the graph (Fig. 2), they can be replotted in the form illustrated in Fig. 3, which shows the intensity, for each area, necessary to elicit an 80 microvolt response from one of the three *S*s. The curves for the other two *S*s were very similar to these. These lines can be described by the equation

$$\log I = -k(\log A) + C, \qquad (1)$$

where I is stimulus intensity, A is the calculated retinal area in sq. mm., $-k$ represents the slope of the line, and C is an intercept constant. This equation can also be expressed in the form

$$I A^k = C', \qquad (2)$$

which is the form in which the results from psychophysical determinations

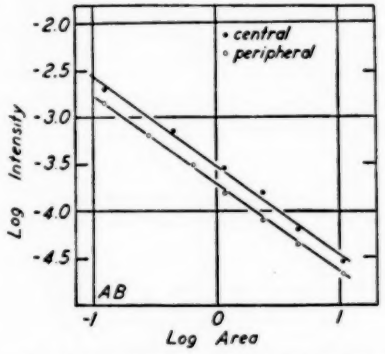

FIG. 3. Combinations of area and intensity required to elicit an 80-microvolt response for subject AB for central and peripheral fixation conditions. Intensity is as specified in Fig. 2; area is in log sq.mm. calculated retinal area (see Table I).

[4] The 80-microvolt criterion was chosen as the smallest value which could be measured with accuracy. Within the linear portion of the curve relating response voltage to log intensity, any other criterion yields similar results.

TABLE II

VALUES OF k IN EQUATION (1) AS A FUNCTION OF CENTRAL AND PERIPHERAL FIXATION

S	Central Fixation	Peripheral Fixation
AB	.95	.93
LH	1.05	.86
WM	.99	.91

of the effect of area upon intensity threshold have customarily been expressed. Table II shows, in summary form, the slope constants k for the three Ss and two fixation conditions.

Comparison of various response measures.—The *B-wave* is used as a measure of retinal response chiefly because of its convenience. Latency (from onset of stimulus to onset of *B-wave* rise) is very difficult to measure accurately. The slope of the *B-wave* rise can also be used as a response measure. In Fig. 4, which shows a sample of some of the original records, it may be seen that the entire *shape* of the response, as well as the height of the *B-wave*, varies under the stimulus conditions. The records also suggest that for any given *B-wave* height, the shape of the response is the same, regardless of the area-intensity combinations used to produce them. Further verification of this notion was established by determining, from one set of records, the intensity-area combinations required to produce a criterion *B-wave* slope. It was found that a criterion slope could be chosen such that the resulting function (log I vs. log A) was exactly the same as that for a given criterion *B-wave*.

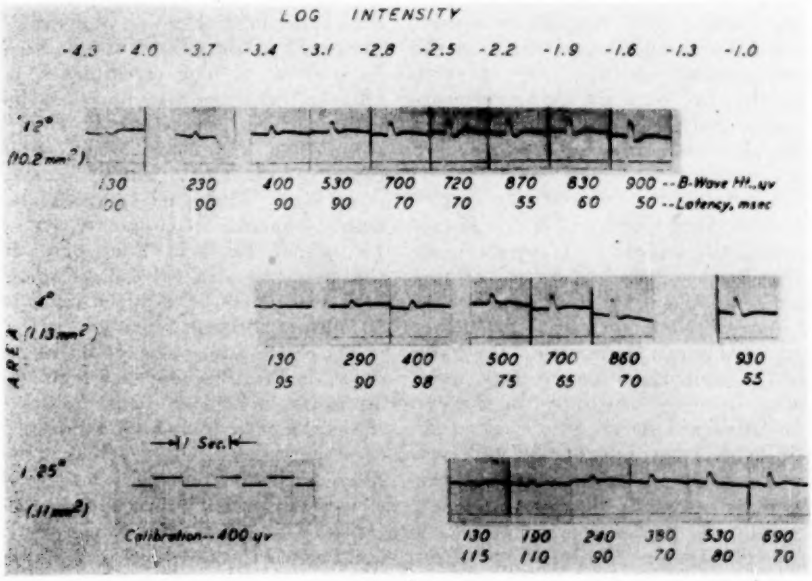

FIG. 4. Specimen records presented in semi-graphical form. The break in the signal line on each record has been placed below the corresponding intensity value used in producing each response. Calibration record shows faithful reproduction of square wave 400 microvolt input to amplifier.

The use of other criterion slopes did not change the slope of the resulting function.

An inspection of Fig. 4 also suggests that a response of a given *B-wave* height will always have approximately the same latency, regardless of the stimulus conditions which led to its production. Also, it may be observed from this figure that an increase in either area or intensity results in (a) an increase in *B-wave* height, (b) an increase in the slope of the *B-wave* rise, and (c) a decrease in the *B-wave* latency. The check on *B-wave* slope described above demonstrated that it could also be used as a response criterion without affecting the results. It is very likely that latency also could be used as a criterion measure if it could be determined with more accuracy. This interchangability of response criteria does not necessarily hold for other experimental conditions. For example, when intensity and time in the dark are the independent variables (**13**), the proportionality between the three measures definitely breaks down, making the choice of a criterion measure more arbitrary.

Central vs. peripheral responses.—Reference to Fig. 3 and Table II discloses only a slight difference between the absolute magnitude of the central as compared to the peripheral responses. No quantitative statements about this can be made on the basis of the main experimental data, however, since the sensitivity of the eye (as measured electrically) varies considerably from day to day, and central and peripheral determinations were never made on the same day during the main experiment. Further checks were made, however, on one *S* (WM). For the 12° area, there was no difference between the central and peripheral responses to otherwise equal stimuli. For the smallest area, a difference was suggested, but its reliability is unknown. Therefore, a further experiment was carried out which demonstrated a significant difference, the peripheral responses being *very slightly larger* than the foveal. For this experiment, the "Maxwellian view" was abandoned in order to eliminate the necessity for re-aligning the eye after each change of fixation. This was accomplished by removing lens L_4 (see Fig. 1) and placing a piece of ground glass adjacent to the diaphragm, on the side nearest L_3. An area of .5° diameter was used for this experiment. The results are shown in Fig. 5, which will be described below.

The blind spot.—For theoretical reasons stemming from the main experiment, stimulation of the blind spot was included as a part of the experiment just described. The blind spot was carefully mapped prior to each experimental session and stimuli presented in the center of this area. In a series of nine experiments, no reliable difference was observed between the responses from blind-spot stimulation and those arising from the stimulation of a nearby area of equal size. The blind spot stimulus was presented at an eccentricity of 15°, about 10° below horizontal in the nasal retina. The peripheral area was chosen at an eccentricity of 20° on the horizontal plane.

The results from one experiment are shown in Fig. 5, where each point for intensities -1.6 and -2.0 represents the mean of at least nine values. A *t*-test performed on the values of responses when the intensity was -1.6 yielded a difference between the peripheral and foveal responses significant well beyond the .001 level. A similar test when the intensity was -2.0 yielded a difference significant at the .05 level. The blind-spot–peripheral

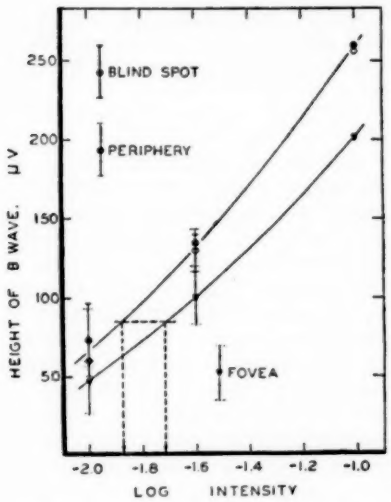

FIG. 5. *B-wave* height as a function of log intensity for foveal, blind-spot, and peripheral stimulation. The plotted values for $I = -1.6$ and $I = -2.0$ represent the mean of at least nine values, whose ranges are indicated. Other points are single determinations.

differences were, as usual, insignificant. Repeats of this experiment, using other peripheral comparisons and two *S*s, gave the same results.

DISCUSSION

No doubt the most striking finding of the main experiment was the discovery that the stimulation of the rod-free area of the fovea, and even that of the blind spot, produced responses which were similar to those resulting from stimulation elsewhere on the retina. This is surprising because there is ample evidence that the major component (*B-wave*) of the human retinal response is primarily a function of the scotopic, or night vision mechanism.[5]

Among the possible mechanisms for the spatial or areal effects of retinal stimulation are neural interaction, volume-conductor spread, and stray light.[6] Neural interaction has been demonstrated in the "four-spot" experiments of Adrian and Matthews (**2**) and has been given a quantitative description in the "receptive field" experiments of Hartline (**12**). This factor appears to be predominant in studies based upon absolute threshold determinations, though the possibility exists that facilitation and inhibition may both play significant parts at high levels of excitation. Volume-conduction, as yet undemonstrated experimentally, is a conceivable mechanism by which electrical activity in one part of the retina may spread to other parts of the retina and there initiate further electrical activity by depolarizing the membranes of nerve cells or other tissues. As explanations for the apparent similarity in the

[5] This assertion is based on the following: (a) the course of dark adaptation, as measured electrically, parallels that of psychophysically determined scotopic dark adaptation (**14**); (b) a similar correlation occurs when electrical and psychophysical determinations of spectral sensitivity are compared (**23, 24**); (c) *S*s with night blindness, including some cases of retinitis pigmentosa, suffer a partial or complete loss of the retinal response (**16**); (d) the *B-wave* is absent under conditions of moderate light adaptation, where cone vision predominates (**25**).

[6] The concept of "stray light" is used here as a general term intended to include scleral transmission, reflection, refractive errors, and intraocular scatter. The scattering of light in media such as those within the eye varies as a function of wavelength (**13, 21**). Hence the importance of this factor seems testable in experiments in which areal effects are related to the wavelength composition of the stimulating light. The notion that stray light is very important in producing the retinal response is not a new one. It was proposed in 1935 by Fry and Bartley (**5**) that stray light accounted for most of the effects observed in experiments on the intact rabbit eye reported at that time. Granit, Rubenstein, and Therman (**10**) very quickly repeated the experiment using an opened eye with the scattering media removed, duplicated Fry and Bartley's results, and argued that neural interaction might equally well be the basis for the results.

effects of directing the stimulus flash at the blind spot and at sensitive retinal areas, both neural interaction and volume-conductor spread are ruled out by the simple fact that where there are no adequate receptors for light, there is unlikely to be any initiation of electrical activity. *Our results, then, clearly support the hypothesis that the sensitive cells elsewhere on the retina are being stimulated, and to an important degree, by stray light.*

The stray light hypothesis, then, assumes that even for stimuli just too weak to produce a measurable retinal potential, the entire retina is being illuminated. As a first approximation, our results can be explained on the assumption that the mean distribution of light over the retina is proportional to total luminous flux (IA) which, in the absence of stray light, would illuminate only the focal area. This implicitly assumes that the effect of the focal flux is very small for the 1° to 12° stimulus patches used in this experiment. This is conceivable when one considers that the focal area is a very small proportion of the whole area served by the scotopic mechanism of the retina.[7]

In brief, then, the stray light hypothesis asserts that the effect of increasing either stimulus area or intensity within the limits of this experiment is to increase the illumination of all the scotopic receptors, including those in the vast non-focal area, and that it is the relatively large number of the elements in this non-focal area which accounts for nearly all the response. Consequently, the measurable latency of the response also indicates primarily the latency of events in the non-focal area.

[7] As noted above, there is a slight, but consistent, departure of the slope constants k, equation (1), from unity for all three *S*s under the peripheral fixation condition. This may well be the result of secondary factors such as local differences in the density and innervation of receptor elements in various portions of the retina.

Summary

Using a contact-lens method of supporting a corneal electrode, the area-intensity combinations required to produce retinal responses of various criterion *B-wave* magnitudes were investigated. Three *S*s were used, with the stimulated area varied with respect to both position and size. Circular stimulus areas with diameters subtending visual angles from 1.25° to 12°, centered foveally, and 30°, peripherally, were employed. Comparisons were also made of responses from stimulation of (a) .5° areas in the fovea, (b) 20° in the periphery, and (c) in the blind spot.

Potentials from the corneal electrode and neutral (forehead) electrode were fed into a direct-coupled amplifier, the output of which was recorded photographically with the aid of a loop oscillograph galvanometer.

The results indicate that: (a) It is possible to obtain sizable responses from stimulation calculated to illuminate only the human fovea or blind spot. The foveal response is slightly but significantly smaller than either the blind-spot or peripheral responses, which are indistinguishable from one another. (b) At a given level of adaptation, responses of a given *B-wave* magnitude have the same latency and are indistinguishable from one another in shape, regardless of the intensity-area combinations used to produce them. (c) The relationship describing the intensity (I) and calculated retinal area (A) combinations necessary to elicit a criterion *B-wave* response is of the type

$$\log I = -k(\log A) + C,$$

over a range of circular retinal areas varying from .11 to 10.2 mm.^{2} (d) The slope constant $-k$ in the above equation has a negative value of unity for central stimulation, and lies between $-.86$ and $-.93$ for 30° eccentric stimulation. (e) The latency of the *B-wave* response (time elapsed between the onset of stimultion and the onset of the *B-wave*) decreases similarly with an increase of either area or intensity.

The results are held to indicate that the human retinal response is primarily aroused by stray light, rather than by the calculated "focal illumination." It is hypothesized that the effect of increasing either stimulus area or intensity within the limits of this experiment is to increase the illumination of the vast "non-focal area," and that it is this non-focal illumination which produces nearly all the response.

(Manuscript received October 20, 1950)

References

1. Adrian, E. D., and Matthews, R. The action of light on the eye: I. The discharge of impulses in the optic nerve and its relation to the electric change in the retina. *J. Physiol.*, 1927, **63**, 378–414.
2. Adrian, E. D., and Matthews, R. The action of light on the eye: III. The interaction of retinal neurones. *J. Physiol.*, 1928, **65**, 273–298.
3. Brown, R. H., and Niven, J. I. The relation between foveal intensity threshold and the length of an illuminated slit. *J. exp. Psychol.*, 1944, **34**, 464–476.
4. Cooper, S., Creed, R. S., and Granit, R. A note on the retinal action potential of the human eye. *J. Physiol.*, 1933, **79**, 185–190.
5. Fry, G. A., and Bartley, S. H. The relation of stray light in the eye to the retinal action potential. *Amer. J. Physiol.*, 1935, **111**, 335–340.
6. Graham, C. H. The relation of nerve response and retinal potential to number of sense cells illuminated in an eye lacking lateral connexions. *J. cell. comp. Physiol.*, 1932, **2**, 295–310.
7. Graham, C. H., Brown, R. H., and Mote, F. A., Jr. The relation of size and intensity in the human eye: I. Intensity thresholds for white light. *J. exp. Psychol.*, 1939, **24**, 555–573.
8. Graham, C. H., and Margaria, R. Area and the intensity-time relation in the peripheral retina. *Amer. J. Physiol.*, 1935, **113**, 299–305.
9. Granit, R., and Harper, P. Comparative studies of the peripheral and central retina: II. Synaptic reactions in the eye. *Amer. J. Physiol.*, 1930, **95**, 211–228.
10. Granit, R., Rubinstein, B., and Therman, P. O. A new type of interaction experiment with the retinal action potential. *J. Physiol.*, 1935, **85**, 34P-36P.
11. Hartline, H. K. The electrical response to illumination of the eye of intact animals, including the human subject and in decerebrate preparations. *Amer. J. Physiol.*, 1925, **73**, 600–612.
12. Hartline, H. K. The receptive field of the optic nerve fibers. *Amer. J. Physiol.*, 1940, **130**, 690–699.
13. Jenkins, F. A., and White, H. E. *Fundamentals of optics*. New York: McGraw-Hill, 1950.
14. Johnson, E. P. The electrical response of the human retina during dark-adaptation. *J. exp. Psychol.*, 1949, **39**, 597–609.
15. Karn, H. W. Area and the intensity-time relation in the fovea. *J. gen. Psychol.*, 1936, **14**, 360–369.
16. Karpe, G. *The basis of clinical electroretinography*. Stockholm, Sweden: O. L. Svanbäcks Boktryckeri Ab., 1945.
17. Monnier, M. L'Electrorétinogramme de l'homme. *EEG clin. Neurophysiol.*, 1949, **1**, 87–108.
18. Page, H. E. The relation between area of stimulation and intensity of light at various levels of visual excitation as measured by pupil constriction. *J. exp. Psychol.*, 1941, **29**, 177–201.
19. Piéron, H. De la sommation spatiale des impressions lumineuses au niveau de la fovea. *Année psychol.*, 1929, **30**, 87–105.
20. Piper, H. Über die Abhängigkeit des Reizwertes leuchtender Objeckte von ihrer Flächen-bezw. Winkelgrösse. *Z. Psychol.*, 1903, **32**, 98–112.
21. Rayleigh, Lord. On the light from the sky, its polarization and colour. *Philosophical Magazine* (Fourth Series), 1871, **41**, 107–120.
22. Ricco, A. Relazioni fra il minimo angolo visuale e l'intensità luminosa. *Ann. Ottol.*, 1877, **6**, 373–479.

23. Riggs, L. A. Continuous and reproducible records of the electrical activity of the human retina. *Proc. Soc. exp. Biol. N. Y.*, 1941, **48**, 204–207.
24. Riggs, L. A., Berry, R. N., and Wayner, M. A. A comparison of electrical and psychophysical determinations of the spectral sensitivity of the human eye. *J. opt. Soc. Amer.*, 1949, **39**, 427–436.
25. Riggs, L. A., and Johnson, E. P. Electrical responses of the human retina. *J. exp. Psychol.*, 1949, **39**, 415–424.
26. Sachs, E. Die Aktionsströme des menschlichen Auges, ihre Beziehung zu Reiz und Empfindung. *Klin. Wschr.*, 1929, **8**, 136–137.
27. Wald, G. Area and visual threshold. *J. gen. Physiol.*, 1937, **21**, 269–287.

THE EFFECT OF A CHANGE IN DIRECTION OF RESULTANT FORCE ON SOUND LOCALIZATION: THE AUDIOGRAVIC ILLUSION [1]

BY ASHTON GRAYBIEL AND J. I. NIVEN

U. S. Naval School of Aviation Medicine, Pensacola, Florida

If a person, who is in a fixed position on a human centrifuge, is subjected to centripetal force, he will tend to reorient himself in conformity with the resultant of this force and the force of gravity. Thus, he will have the illusion that he has shifted his position with reference to the vertical, and objects in the visual field will appear to have assumed new positions in space (1). Whether, under these circumstances, a person also tends to relocalize a source of sound is the subject of this report. Insofar as we are aware, there have been no previous investigations of this specific problem. However, it is closely related to other illusory phenomena which are based on a similar psychophysiological mechanism (2).

Apparatus and Procedure

The experimental design required that *S* be subjected to a change in direction of resultant force, which was greater than *S*'s error in localizing a source of sound. In the human centrifuge, the resultant force can be changed in only one plane with respect to *S*. This is obviously the plane passing through the axis of the centrifuge. If *S* is facing the center of the centrifuge, the force can be moved in his median or sagittal plane; if he is turned at right angles to this, the force moves in his frontal plane. In neither plane can he localize well, so a simple expedient was adopted to bring the change of force and, hence, the expected illusion into the "horizontal" plane for his ears. The expedient was to have *S* tilt his head to one side by an angle of 90° while he sits facing the center or away from the center of the centrifuge.

The centrifuge was of the inertia-wheel type which has been described previously (3). A small, sound-insulated chamber was mounted on one arm of the centrifuge. It was constructed of aluminum alloy and formed a sphere except at the base where a segment, comprising 90° of arc, was replaced by a cylinder 3 ft. in diameter and 9 in. high. The chamber was lined with three layers of soundproofing material, the innermost consisting of corrugated wool felt. The floor was covered with a felt carpet.

Matched dynamic earphones (ANB-H-la) were placed at 5° intervals of arc in a circle which divided the sphere into right and left halves. This circle was complete except for the segment of 90° at the base. The plane of this circle was the same as that in which the change in direction of resultant force occurred during centrifugation.

Each earphone was connected with a Maico audiometer on a separate circuit connected to a central switchboard. The stimulus tone of 1024 cps was presented for .1 sec. The onset of the tone involved only a weak transient; the cessation, however, was accompanied by a definite click.

The *E* and control panel were located at the central column of the centrifuge. The *E* maintained a positive check on the presentation of the stimulus by means of a signal light which flashed during the period when the circuit was complete. A one-way communication system allowed *S* to speak to *E*; the latter could signal *S* by means of flashing lights to indicate the beginning and ending of an experimental session.

Within the chamber was a seat so designed that *S* could sit with head inclined 90° toward the shoulder. The position of the head was maintained by means of an adjustable metal helmet lined with foam rubber; the rim of the helmet was in contact with but did not overlap the upper edge of the external ear. A padded arm rest beneath the headpiece provided an additional means of support. At the highest level of acceleration *S* required the use of a hand-hold mounted on the chamber wall. The center of *S*'s head was in the center of the sphere which was 16.8 ft. from the center of rotation. A line

[1] This paper is a slightly modified version of BuMed Report No. NM 001 059.01.23. Opinions or conclusions contained therein are those of the authors. They are not to be construed as necessarily reflecting the view or the endorsement of the Navy Department.

passing through *S*'s ears coincided with the vertical axis of the sphere.

Four healthy men with normal hearing served as *S*s. Each was thoroughly familiar with the experimental procedure and three of the four had previous experience with disorientation effects due to acceleration. Two seating positions were used; in one *S* faced toward and in the other he faced away from the center of rotation. Each *S* was tested when the centrifuge was stationary and at each of three levels of acceleration; the angular displacements of the resultant force from the vertical (denoted as the angle ϕ) were 11.4°, 19.7°, and 29.2°. Under each of these four conditions *S* was required to estimate the location of one of four different target positions. The first or zero position was directly before him. The other positions were 15° below and 15° and 30° above the zero point.

In the experimental trials the three variables concerned, seat position, magnitude of acceleration and tone position, were counterbalanced. A modified method of limits was used for determining *S*'s estimation of the several target positions. First, *S* was informed which of the four positions he was to localize. He was then presented with a succession of stimulus tones beginning well away from this point and gradually sweeping toward it. The *S*s were instructed to respond with "no" to all incorrect stimuli, and "yes" when they judged that the direction of the stimulus tone coincided with that of the target position they were to localize. Because of the ease of confusion, they were cautioned to refer the stimuli at all times to what seemed to be the true horizon. A common source of difficulty in disorientation experiments is that different *S*s, or even the same *S* at different times, may shift the reference point from what seems to be the true horizon to what it is "known" to be after compensating for the effects of acceleration.

All judgments were made with the eyes open but in darkness to rule out the influence of visual cues. Two judgments were made, one in which the approach was made from below and one from above the target position. Two judgments for each of the four positions constituted an experimental trial. Eight such trials comprising all combinations of seating positions and levels of acceleration were given each *S*. A rest period of at least 30 min. was allowed between trials.

Results

The mean estimated position of a sound source at various target positions is presented in Table I for each of the experimental values of acceleration (defined in terms of the resultant angle ϕ) used. The table shows that when *S* faced toward the center of rotation he localized a source of sound as coming from "below" its true location. When *S* faced away from the center of rotation, the direction of displacement was consistently "upwards." The displacement was of the same magnitude but opposite in sign as when *S* faced toward the center of rotation. At any given level of acceleration the arithmetical sum of the displacements represents the maximum range of error of localization when *S* reverses the position of his body with respect to the direction of the resultant force.

The results further indicate that the displacement of a sound source in the absence of visual cues is a linearly increasing function of the resultant

TABLE I

Mean Estimated Position of Tone as a Function of True Position, Acceleration, and Seating Position

True Position in Degrees	Acceleration (Resultant Angle ϕ*)						
	−29.2	−19.7	−11.4	0	11.4	19.7	29.2
30	0.6	11.9	20.6	28.1	38.1	46.2	53.1
15	−1.2	0.6	12.5	15.0	26.9	30.6	34.4
0	−16.2	−13.1	−7.5	1.9	8.1	23.8	21.9
−15	−31.9	−26.2	−20.0	−12.8	−8.8	0.6	3.1

* Minus values relate to data obtained when *S* faced the center of rotation and positive values when *S* faced away from the center of rotation. Data from both positions were combined when ϕ was zero degrees.

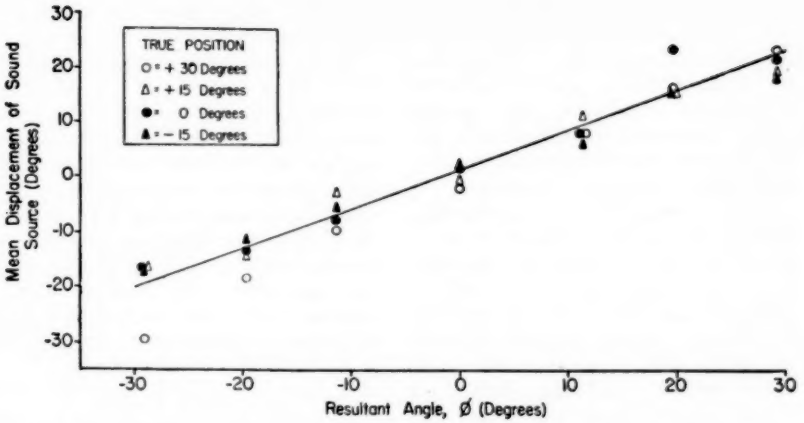

FIG. 1. Mean displacement of a sound source, at various positions with respect to the "horizon," as a function of resultant angle. Each datum represents the mean of eight observations.

angle associated with a given level of acceleration. Figure 1 shows mean displacement, obtained by subtracting the target position in degrees from the estimated position in degrees, as a function of resultant angle. The data are fitted with an empirical function $\phi_a = .69\ \phi + 1.7$, where ϕ_a = mean displacement, ϕ = resultant angle, and all measurements are expressed in degrees of arc. It may be seen that the displacements obtained when the target position is 30° above the horizon and *S*s are facing toward the center of rotation, i.e., the resultant angle is negative, seem to deviate from the general trend.

The data were subjected to tests for zero slope, linearity of regression, and goodness of fit (**4**, p. 281). An *F* of 86.03 with 6 and 18 *df* justified the rejection of the hypothesis of zero slope. *F* ratios of .86 and .83 with 5 and 18 *df* were obtained in testing linearity and goodness of fit. These values were far below the 2.77 required to show a significant difference at the .05 level of confidence, and the hypothesis that the fitted curve represents the data adequately was sustained. Hence, the variation of the experimental data from the best-fit curve can be attributed to chance.

DISCUSSION

These data have shown that, under the experimental conditions described, the localization of a source of sound in terms of a vertical-horizontal frame of reference, is influenced by the change in direction of resultant force. This phenomenon has been termed the audiogravic illusion. The apparent displacement is quite uniform within the range tested. A linear relationship was found to exist between the amount of apparent displacement and the angle ϕ; the former amounts to approximately 70 per cent of the angle ϕ in degrees.

The audiogravic illusion is readily explained as follows. Under static conditions and in the absence of visual cues *S* judges the position of a stimulus tone with reference to a point on the horizon directly before him. Now the estimation of the horizontal

and vertical axes depends, fundamentally, on cues which orient a person to the direction of gravity. These arise by virtue of direct contact with the supporting structures and include stimuli from sensory elements in the non-acoustic labyrinth, muscles, tendons, joints, skin, and elsewhere.

Under conditions of acceleration these same sensory organs orient a person in the direction of resultant force. Inasmuch as *S* in our experiment was not free to change position there was a change in angle between the body axis and resultant force; accordingly he had the illusion of feeling that he was tilted. The egocentric localization of the vertical and horizontal axes now accords with the direction of resultant force and not the true vertical. Hence, the localization of a point source of sound within this frame of reference would cause *S* to be in error with respect to the true position of the stimulus.

Summary

An experiment was carried out in which four male *Ss* estimated the location of a source of sound while being subjected to a change in direction of resultant force with respect to themselves.

A consistent error was made in terms of a non-visual vertical-horizontal frame of reference. The error amounted to about 70 per cent of the angle ϕ and a linear relationship was found to exist between the two.

This phenomenon has been termed the audiogravic illusion and it can be readily explained on the basis that the egocentric localization of the horizon, under the conditions of our experiment, accords with the change in direction of resultant force.

(Manuscript received
September 25, 1950)

References

1. Mach. E, *Grundlinien der Lehre von den Bewegungsempfindungen.* Leipzig: Wilhelm Engelmann, 1875.
2. Clark, B., and Graybiel, A. The effect of angular acceleration on sound localization: The audiogyral illusion. *J. Psychol.*, 1949, **28**, 235–244.
3. Graybiel, A., Kerr, W. A., and Bartley, S. H. Stimulus thresholds of the semicircular canals as a function of angular acceleration. *Amer. J. Psychol.*, 1948, **61**, 21–36.
4. Lewis, D. *Quantitative methods in psychology.* Iowa City: The Bookshop, 1949.

THE GENERALIZATION GRADIENT IN RECOGNITION MEMORY[1]

BY LEO POSTMAN

University of California

There is considerable experimental evidence for stimulus generalization in verbal learning and retention. Once an association has been formed between a stimulus and a verbal response, stimuli other than the one used in the original training will evoke the response. The greater the change in the stimulus, the less frequently does the original verbal response occur. A gradient of stimulus generalization is obtained when frequency of response is plotted against degree of similarity between training stimulus and test stimulus (**3, 4, 8, 14**). These results suggest a strong parallel between the behavior of verbal responses and conditioned autonomic responses in human *S*s, where generalization along various dimensions of stimulus similarity has been demonstrated (**5, 6, 11, 12**).

Previous experiments have been concerned with the evocation of specific verbal responses by stimuli varying along a dimension of similarity. No comparable effects of stimulus generalization have been demonstrated for recognition memory. The following analysis of the stimulus-response relationships in a recognition situation leads to the prediction that a gradient of stimulus generalization should be demonstrable in recognition memory.

Let us assume, in agreement with Gibson, that "a major necessity of verbal learning is the establishment of discrimination among the items to be learned" (**2**, p. 197). Stimulus generalization facilitates learning (aids in the establishment of the necessary discriminations) if the generalizing stimulus items require the same responses. Stimulus generalization impedes learning if the generalizing items require different responses. In the case of *recognition*, the discrimination which *S* must make is between the correct and incorrect items on the recognition test. All the correct items require the same response–recognition (identification as correct). By the same token, all the incorrect items require the same response–non-recognition (identification as incorrect). Applying Gibson's hypothesis, we can make the following deductions concerning the effects on recognition of similarity relationships among the stimuli.

1. *Degree of similarity among correct stimuli.*—Since all the correct stimuli require the same response–recognition, generalization by similarity among these items will strengthen that common response. The more similar the correct items are to each other, the more is the common response of recognition strengthened.

2. *Degree of similarity among incorrect stimuli.*—The more similar the incorrect items are to each other, the more the response of non-recognition (identification as incorrect) generalizes among these items. Here again similarity strengthens the common response.

[1] This research was facilitated by a grant from the Laboratory of Social Relations at Harvard University. The writer expresses his thanks to Miss Jacqueline Jarrett for her assistance in the experimental work.

3. *Degree of similarity between correct and incorrect stimuli.*—Correct and incorrect stimuli require different responses. The greater the similarity between the two classes of stimuli, the more difficult is the discrimination among them and the more frequently will incorrect items be identified as correct (and vice versa).

It is with the last of these relationships that the present experiment is concerned. The hypothesis to be tested is that a gradient of stimulus generalization, analogous to the gradients in conditioning and paired-associate learning, obtains in recognition memory. For purposes of this experiment, degree of similarity will be defined in terms of the number of elements (letters) common to correct and incorrect stimuli. Since the learning materials were nonsense words, such a definition of similarity is supported by its proven usefulness in past experiments, notably in the fields of transfer and retroactive inhibition (**13, 14**). The experimental hypothesis may, then, be restated as follows: the larger the number of elements common to correct (originally learned) and incorrect (new) items, the higher the probability that the recognition response will be aroused by the incorrect items.

Procedure

Original learning.—The *S*s learned a series of 24 six-letter nonsense words which were so constructed as to yield a thoroughly randomized distribution of consonants and vowels, both with respect to the frequency of use of different letters and their positions in the words. No sequence of two or more letters appeared more than once in the list. Examples of such words are: RIJKAF, DACTUV, TEFZOK.[2] Each word was printed in solid capitals (1 in. high) with heavy black india ink on white cards (3 × 10 in.).

For the learning, *S*s were given the following instructions: "I am going to show you a series of six-letter nonsense words, i.e., words which have no dictionary meaning. I want you to watch carefully since your memory for these words will be tested. The series will be shown several times, each time in a different order. Do not try to memorize any of the orders since you will not be required to remember them in any particular order. Just concentrate on the words themselves."

The cards were exposed to the group at a 2-sec. rate. The series was presented six times, each time in a different random order, with an interval of 10 sec. between series.

Recognition test.—Immediately following the original learning, *S*s were given a recognition test. The following 48 items appeared on the recognition test:

- 6 words from the original list, unchanged.
- 6 words from the original list, with one of the letters changed.
- 6 words from the original list, with two consecutive letters changed.
- 6 words from the original list, with three consecutive letters changed.
- 24 unrelated words, i.e., that did not have a sequence of two or more letters in common with either the original words or the variations of the original words which appeared on the recognition test. The unrelated words had, on the average, 1.3 letters in common with the learning items.[3]

The 24 words on the learning list were thus broken down into four groups of six, each group representing a different degree of similarity (defined by number of common elements) to the original words. The number of common elements ranged from six (no change) to three (three-letter change). Care was taken that none of the variations had two or more letters in common with any word other than the one from which it was derived. For each type of change, the positions within the word at which the alterations were made were systematically varied. Thus, one-letter changes were made at each of the six possible positions within the word; consecutive two-letter changes were made at positions 1–2, 2–3, 3–4, 4–5, 5–6; finally, consecutive three-letter changes were made at positions 1–2–3, 2–3–4, 3–4–5, 4–5–6. The fre-

[2] The original learning lists and the recognition tests may be obtained by ordering document 3406 from the American Documentation Institute, 1719 N Street, N.W., Washington 6, D. C., remitting $1.00 for 35 mm. microfilm or $1.00 for 6 × 8 in. photocopies.

[3] In the case of each learning item, the average number of elements common to it and all the unrelated items was determined. The grand mean for the four recognition tests was 1.3.

quency of different positions of change was equalized as closely as possible.

To control for differences in difficulty, the original list of 24 was divided into four groups of words, and each of the four groups of words was subjected to all the possible changes, with frequencies of different positions of change equalized.[4] Four recognition tests were then constructed so that each type of change was applied to each group of words. Each *S* received, of course, only one of the recognition tests. Tests were assigned to the *S*s at random, and the different tests were used equally often.

Each *S* was handed a recognition sheet on which the 48 test items were arranged in random order as well as a record sheet with spaces numbered consecutively from 1 to 24. The sheets were face down, and before being allowed to turn them over, *S*s were given the following instructions: "On this sheet you will find a list of 48 six-letter nonsense words, numbered consecutively from 1 to 48. Among these are words which you have just seen as well as some new nonsense words. I want you to go through this list and pick out the words which you recognize as having been in the list you have just seen. As soon as you recognize a word, write its number in one of the spaces provided for that purpose on the record sheet which you have before you. It is your job to pick out a total of 24 words. If on the first reading of the list you have not picked out 24, start again and continue through the list until you have copied 24 numbers to your record sheet. It may be necessary for you to guess in order to fill your quota of 24 items. We do want you to guess if necessary. Experiments have shown that when people guess on such a test, they are more often right than wrong. Be sure to pick out exactly 24 words, no more, no less. When I say 'Go,' turn over your recognition sheets and start picking out the words you recognize. Try to work as fast and as accurately as you can. As soon as you have finished, turn your sheets over. Ready—Go!"

The requirement to pick out 24 items requires comment. The main purpose of the experiment was to demonstrate a gradient of generalization in recognition memory. It was desirable, therefore, to maximize *S*s' attempts at discrimination. There is evidence from experiments on psychophysical judgment (1) and recognition memory (9) that *S*s who are forced to guess do better than can be expected on a chance basis. Instructions to guess, therefore, test the limits of *S*'s abiiity to discriminate. Since *S*s vary in the standards of subjective certainty which they require for recognition responses, such a procedure tends to equalize the criterion on which the responses of different *S*s are based. Most of the *S*s were not aware of the fact that many of the original items had been changed. The data of those who were aware of the fact that changes had been introduced will be treated separately.

Subjects.—The *S*s were 36 undergraduate students who had volunteered to serve. They did not know the purpose of the experiment.

Results and Discussion

Recognition scores.—We shall first consider the results for those *S*s who stated after the experiment that they did not realize that many of the original items had been changed on the test. We shall refer to these *S*s as the *Recognition Group*. There were 30 *S*s in the Recognition Group, seven each in two of the subgroups and eight each in the other two subgroups. A group of six *S*s did become aware of the changes during the test and then proceeded to choose items in accordance with perceived similarity to the original ones. The latter group will be referred to as the *Judgment Group*.

Table I shows the average number of items chosen from each of the categories of words on the recognition test by the Recognition Group. These averages were converted into percentages and are presented graphically in Fig. 1.[5] Clearly, the larger the number of elements common to the learning items and the test items, the more frequently are the test items chosen in the recognition test. The graph in Fig. 1 thus represents a gradient of stimulus generalization in the recognition of verbal stimuli when number of common elements defines the dimension of generalization.

An analysis of variance was performed on the recognition scores to

[4] When the number of test items was even (six) and the number of different positions was odd, it was not possible completely to equalize the frequency of different positions of change.

[5] The per cent choices of unrelated items is plotted against the point representing 1.3 common elements.

TABLE I

MEAN NUMBER AND PER CENT OF RECOGNITION RESPONSES AS A FUNCTION OF SIMILARITY

No. of Common Elements	Recognition Group		Judgment Group	
	Mean	%	Mean	%
6 (6 items)	5.73	95.5	5.83	97.2
5 (6 items)	5.00	85.3	5.17	86.2
4 (6 items)	3.67	61.2	4.00	66.7
3 (6 items)	2.40	40.0	2.83	47.2
1.3 (24 items)	7.23	30.1	6.17	25.7

determine the significance of the trend depicted in Fig. 1. Degree of similarity (number of common elements) is a highly significant source of variance ($F = 93.1$, $df = 4$ and 116, $p < .01$).[6] Differences among subtests, on the other hand, fall far short of significance as does the interaction of subtests × similarity. The general relationship between similarity and recognition is independent, therefore, of the particular groups of words to which the various changes are applied.

The recognition scores of the *Ss* in the Judgment Group are also shown in Table I and are represented graphically by the dashed line in Fig. 1. The results of the Judgment Group closely parallel those of the Recognition Group. Analysis of variance again showed degree of similarity to be a highly significant source of variance ($F = 30.51$, $df = 4$ and 20, $p < .01$).

Comparison of Recognition and Judgment Groups.—The Judgment Group recognized correct and partly changed items more frequently than did the Recognition Group. The members of the Judgment Group were *Ss* with better average retention and hence were more likely to discover the discrepancy between learning items and test items. The *shape* of the generalization gradient, however, is very much alike for both groups. There is thus no basic difference between the recognition behavior of the Recognition Group and the Judgment Group. For both groups, frequency of recognition responses describes a generalization gradient as a function of similarity between original items and test items. The results are independent, therefore, of *S*'s "insight" into the procedure. The parallel results for the two groups also serve to emphasize the continuity of principles governing judgment and retention (**10**).

Shape of the gradient.—In plotting the gradient, we have used number of common elements as our definition of similarity. The shape of the gradient may well be different when similarity is defined in more complex psychological terms such as semantic meaning (**7, 12**) and configurational properties of stimuli (**11**). The effect of stimu-

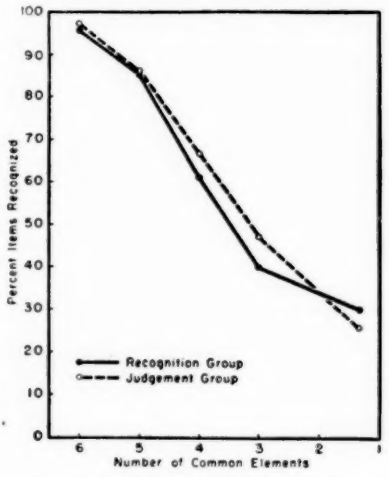

FIG. 1. Per cent recognition responses as a function of the number of elements common to test items and original learning items

[6] Since the interaction, subtests × similarity, was not significant, it was pooled with the error in determining the *F* value.

lus generalization on recognition memory has, however, been demonstrated in principle.

Continuity of recognition and other forms of retention.—Since stimulus generalization has been previously demonstrated in paired-associate learning, our present results add to the evidence for the continuity of various types of retention behavior. At the same time, the existence of common principles in verbal learning and conditioning is reaffirmed.

Summary

The purpose of this experiment was to demonstrate a gradient of stimulus generalization in recognition memory. The hypothesis was tested that the greater the similarity between correct and incorrect items, the higher is the probability that a recognition response will be given to the incorrect item. Degree of similarity was defined in terms of the number of letters common to the correct and incorrect stimuli.

A list of 24 six-letter nonsense words was presented six times, each time in a different random order. Retention was tested immediately thereafter by a recognition test of 48 items, in which there were groups of six items representing 0-, 1-, 2-, and 3-letter changes from the original items and a group of 24 items unrelated to the original learning items.

The larger the number of elements common to original learning items and test items, the more frequently were the test items chosen on the recognition test. Frequency of recognition responses describes a gradient of stimulus generalization.

The results confirm the view that recognition performance varies directly with the discriminability of learning items and test items.

(Manuscript received October 21, 1950)

References

1. Brown, W. The judgment of difference. *Univ. Calif. Publ. Psychol.*, 1910, **1**, No. 1.
2. Gibson, E. J. A systematic application of the concepts of generalization and differentiation to verbal learning. *Psychol. Rev.*, 1940, **47**, 196–229.
3. Gibson, E. J. Retroactive inhibition as a function of degree of generalization between tasks. *J. exp. Psychol.*, 1941, **28**, 93–115.
4. Gulliksen, H. Transfer of response in human subjects. *J. exp. Psychol.*, 1932, **15**, 496–516.
5. Hovland, C. I. The generalization of conditioned responses: I. The sensory generalization of conditioned responses with varying frequencies of tone. *J. gen. Psychol.*, 1937, **17**, 125–148.
6. Hovland, C. I. The generalization of conditioned responses: II. The sensory generalization of conditioned responses with varying intensities of tone. *J. genet. Psychol.*, 1937, **51**, 279–291.
7. McGeoch, J. A., and McDonald, W. T. Meaningful relation and retroactive inhibition. *Amer. J. Psychol.*, 1931, **43**, 579–588.
8. McKinney, F. Quantitative and qualitative essential elements of transfer. *J. exp. Psychol.*, 1933, **16**, 854–864.
9. Postman, L., Jenkins, W. O., and Postman, D. L. An experimental comparison of active recall and recognition. *Amer. J. Psychol.*, 1948, **61**, 511–519.
10. Pratt, C. C. The law of disuse. *Psychol. Rev.*, 1936, **43**, 83–93.
11. Razran, G. Studies in configural conditioning: V. Generalization and transposition. *J. genet. Psychol.*, 1940, **56**, 3–11.
12. Razran, G. Semantic and phonetographic generalizations of salivary conditioning to verbal stimuli. *J. exp. Psychol.*, 1949, **39**, 642–652.
13. Robinson, E. S. The "similarity" factor in retroaction. *Amer. J. Psychol.*, 1927, **39**, 297–312.
14. Yum, K. S. An experimental test of the law of assimilation. *J. exp. Psychol.*, 1931, **14**, 68–82.

DRIVE LEVEL AND REINFORCEMENT

BY JAMES DEESE AND J. A. CARPENTER

The Johns Hopkins University

In the past ten years many investigators have studied the relationship between effectiveness of reinforcement and the level of drive under which this reinforcement was given. Typically, in these studies, animals are conditioned to press a lever under various different levels of drive and then are extinguished under a common level of drive. The number of responses in the extinction period is taken as the measure of the effectiveness of reinforcement under various drive levels. Most frequently the effect of a reinforcement appears to be independent of the level of drive under which it is given (**4, 5, 6**). On the other hand, Finan (**2**) found that animals conditioned under 12-hr. food-deprivation showed significantly more responses in extinction than did animals conditioned under 1-hr. deprivation. However, animals conditioned under 24- and 48-hr. deprivation showed less resistance to extinction than did animals conditioned under 12-hr. deprivation.

The present experiment is designed to further explore the relationship between learning and level of drive under which it occurs. That this problem bears a very important relationship to at least one of the problems in latent learning experiments has been discussed elsewhere (**1**).

PROCEDURE

The measure of response strength was the latency (in .01 sec.) of a running-response in a simple, enclosed, 3-ft. long runway. The starting box and runway were painted gray, while the goal-box was black and was slightly larger than the starting box and alley. A sliding door between the starting box and the runway activated a timer when it was opened by *E*. The rat interrupted a beam of light to a photoelectric cell located 5 in. from the starting door, which stopped the timer. Thus, the actual time measured was that from the opening of the door to the interruption of the light-beam by *S*.

The *S*s were 30 pigmented rats of the Lashley strain, raised in the Johns Hopkins colony. All *S*s were placed on a 24-hr. feeding schedule nine days before the beginning of the experiment. They were allowed access to wet bran-mash for 1 hr. during the day. The *S*s were divided into two groups of 15. One group was given four trials per day immediately following 1 hr. of access to bran-mash in the home-cage (low drive). The other group was given four trials a day, just prior to the 1-hr. feeding period (high drive). The same wet mash was available in a feeding dish in the goal-box. When *S* reached the goal-box at the end of each trial, it was allowed to remain and feed from the mash for 1 min. All but one *S*, and then only on one trial, nibbled at the food during training under low drive. The four trials were given with rest intervals of 2 min. between trials.

The critical point in the experiment occurred when the drive-level was reversed for the two groups after Trial 24. The low-drive group now received its training before feeding, and the high-drive group now was fed first and then trained on the runway. Following the reversal of drives, eight more trials were given.

RESULTS

In Fig. 1 are plotted reciprocals of the mean log latencies of all trials for both groups. The *S*s trained under low drive show little systematic change during the initial 24 trials. The *S*s trained under high drive show a rapid initial improvement, but reach an asymptote around Trials 13 or 14. Despite the fact that the data are variable, there is a consistent difference between the *S*s trained under low drive and under high drive. The t for the difference between mean log latencies on Trial 24 is 3.28 ($p = .001$).

After the reversal of drive levels, *S*s previously trained under low drive

immediately reach the asymptote established by the Ss under high drive. Performance on this first test trial with changed drive is very important since it reflects only the change in drive, which has not yet been confounded with reinforcement under the changed drive. The remaining seven test trials represent the joint influence of the high drive and reinforcement under high drive. However, the fact that these Ss immediately reached the asymptote established by Ss trained under high drive indicates that the training under low drive had been as effective as that under high drive.

Statistical confirmation of this observation demands a word of explanation. Cyclical fluctuations appear in both curves in Fig. 1. The cycles correspond almost entirely with the four trials given each day; the first trial of the day usually shows the highest performance and the last trial the lowest performance. This could be a result of (a) the 3-min. feeding period which intervenes between these trials or (b) the massed practice. Whatever may be the reason, Trial 21 represents a better index of performance under original drive than does Trial 24. The difference in mean log latency between Trial 21 under low drive and Trial 1 under high drive is significant at the .05 level ($t = 2.26$). The corresponding difference between Trial 24 and Trial 1 is also significant at the .05 level ($t = 2.53$).

The Ss originally trained under high drive present a different picture, however, when switched to low drive. To be sure, they show a slight decrease in performance; however, they do not decline immediately to the asymptote

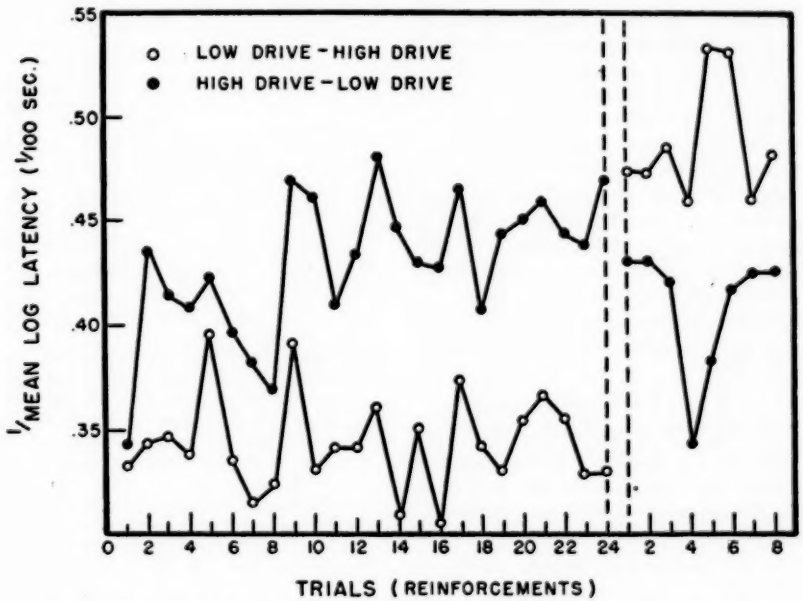

FIG. 1. Reciprocals of mean log latencies of a running response as a function of training under low and high hunger drive and test under reversed drives

of the *Ss* trained under low drive. The departure from the asymptote established under high drive is not statistically significant. The *t* between Trial 24 under high drive and Trial 1 under low drive is only .47. However, the *t* between Trial 1 under low drive and Trial 24 of *Ss* trained under low drive is 2.46 ($p = .02$). The *t* between Trial 1 under low drive and Trial 21 of *Ss* trained under low drive is 2.12 ($p = .05$).

Discussion

When animals trained on low hunger drive are switched from a low drive to a high drive, they perform as well as though they had been trained on high hunger drive. In other words there does not seem to be an effect of drive level upon the effectiveness of reinforcement, as measured by response latency. If the need-reduction hypothesis (**3**) is correct, it would appear that the amount of need-reduction per reinforcement does not depend upon the absolute level of drive. Indeed, the lack of relationship between the effectiveness of reinforcement and drive-level, indicated by this and other studies (**4, 5, 6**), suggests that the drive-reduction hypothesis may not be correct. In this sense, the present study is in direct accord with those latent learning studies which consider drive as a variable and which achieve positive results (**7**).

Summary

Thirty rats were trained for four trials per day to obtain wet bran-mash placed in a goal-box at the end of a simple runway. Latencies of the running response were recorded as measures of response strength. Half of the *Ss* were given trials in the runway immediately before their daily feeding (high drive), and half were given their trials in the runway immediately after the daily feeding (low drive). After 24 trials the drive levels of the two groups were reversed. The *Ss* trained under low drive reached the asymptote of the *Ss* trained under high drive immediately after being placed on high drive. Since this observation was uncontaminated by reinforcement under high drive, it appears that the effect of reinforcement is independent of the level of drive.

Those *Ss* trained under high drive, however, failed to depart significantly from the asymptote previously established when the drive was shifted. They certainly did not approach the asymptote predicted by the *Ss* trained originally under low drive.

(Manuscript received October 24, 1950)

References

1. Deese, J. A quantitative derivation of latent learning. *Psychol. Rev.*, 1950, **57**, 291–294.
2. Finan, J. L. Quantitative studies in motivation: I. Strength of conditioning in rats under varying degrees of hunger. *J. comp. Psychol.*, 1940, **29**, 119–124.
3. Hull, C. L. *Principles of behavior.* New York: D. Appleton-Century, 1943.
4. Kendler, H. H. Drive interaction: II. Experimental analysis of the role of drive in learning theory. *J. exp. Psychol.*, 1945, **35**, 188–198.
5. Reynolds, B. The relationship between the strength of habit and the degree of drive present during acquisition. *J. exp. Psychol.*, 1949, **39**, 296–305.
6. Strassburger, R. C. Resistance to extinction of a conditioned operant as related to drive level at reinforcement. *J. exp. Psychol.*, 1950, **40**, 473–487.
7. Thistlethwaite, D. A critical review of latent learning and related experiments. *Psychol. Bull.*, 1951, **48**, 97–129.

THE EFFECT OF REINFORCEMENT ON CLOSELY FOLLOWING S–R CONNECTIONS: I. THE EFFECT OF A BACKWARD CONDITIONING PROCEDURE ON THE EXTINCTION OF CONDITIONED AVOIDANCE [1]

BY MOHAMED O. NAGATY

Yale University

The present experiment is the first of two (**20**) designed to clarify the controversy concerning the effect of a reinforcement on immediately subsequent stimulus-response (S-R) connections. A number of studies on the "spread of effect" (**2, 3, 7, 12, 14, 15, 18, 19, 30, 31, 32, 33, 34**) are interpreted as indicating that there is a gradient of reward spreading to *following* S-R connections, with connections most closely following the reward being more strongly reinforced than those more remotely following it. The existence of such an effect has been questioned by other investigators (**13, 21, 25, 26, 29, 35, 36, 40**). Similarly, a number of studies claim to have secured "backward conditioning," an effect of the reinforcing unconditioned stimulus (UCS) on responses to stimuli *following* it (**27, 28, 37, 38**) but these studies have not been carefully controlled to rule out the possible effects of pseudo-conditioning (**1, 8, 9, 10, 11, 16**), and other investigators have failed to confirm their results (**4, 5, 6, 24, 39**).

In contrast with the claims for the occurrence of a "spread of effect" to subsequent S-R connections or "backward conditioning," Pavlov (**22**, pp. 242–244) reports that presenting the conditioned stimulus (CS) after the UCS produces inhibition analogous to the experimental extinction of a non-reinforced response. Pavlov does not present detailed evidence supporting this claim,[2] nor do the results which he reports disclose the difference between inhibition in the case of reinforcement (UCS) preceding the CS and in the case of non-reinforcement. The typical study on the spread of effect to S-R connections following the reinforcement or on backward conditioning starts at a near zero level of instrumental or conditioned response (CR) and is designed to find whether or not any increase occurs in the strength of the response. Thus, these studies could not be expected to demonstrate any possible inhibitory effect of the reinforcement on subsequent S-R connections.

[1] One of two articles submitted to the faculty of the Department of Psychology of Yale University in partial fulfillment of the requirements for the Ph.D. The writer is greatly indebted to Fouad First University of Cairo, Egypt, for financial support; and to Professor Neal E. Miller, under whose guidance this investigation was performed, for his generous advice and valuable suggestions throughout the course of the experiment and preparation of the manuscript. The writer wishes also to thank Dr. Fred D. Sheffield for reading and criticizing the manuscript, and Mr. Robert Grose for assistance in constructing the experimental apparatus.

[2] It should also be noted that Pavlov in a later publication (**23**, p. 381) reports that if a neutral stimulus is presented after a reinforcing UCS, a conditioned reflex may develop; but he describes it as "insignificant and evanescent." On continuing the procedure, Pavlov reports, the stimulus becomes inhibitory. This contention was recently supported by Spooner and Kellogg who described backward conditioning as ". . . a process which builds up inhibitions, rather than one which builds up or strengthens an active overt CR" (**27**, p. 330).

The purpose of the present experiment is to study in an avoidance conditioning situation: (a) the inhibition which Pavlov claims is produced by applying the CS after the UCS, and (b) the authenticity of the claimed after-gradient of reinforcement in both "spread of effect" and "backward conditioning" phenomena.

Subjects and Apparatus

Subjects.—The *S*s were 40 male albino rats 65 to 100 days old, all of which had satisfied a criterion of preliminary training and conditioning. Eight more *S*s were discarded for failure to meet this criterion. The *S*s were randomly assigned to three experimental groups of 12 *S*s each, and a special control group of four *S*s.

Apparatus.—A buzz-shock avoidance conditioning technique was used. The CS was a loud buzzer; the UCS was an electric shock of 240 v. delivered through a series resistance of 200,000 ohms, and the CR was rotating a wheel which turned off the buzzer and immediately turned off the shock or prevented the shock from occurring.

The apparatus consisted of a narrow enclosure, the inside dimensions of which were approximately $4\frac{5}{16} \times 4\frac{1}{2} \times 8$ in. The front of this enclosure was built of glass to permit *E* to watch the animals. The right side had an opening approximately $3\frac{1}{4}$ in. wide and $3\frac{1}{2}$ in. high through which a wheel was placed in such a way that the rats could easily turn it with their front paws from inside the enclosure. At the left side of the enclosure opposite to the wheel there was an inclined metal wall which curved towards the right side and ended above the wheel. The purpose of this inclined wall was to minimize the random behavior of the rat and to force him to stay as close as possible to the wheel. The floor of the enclosure was a grid made of stainless steel rods $\frac{1}{16}$ in. in diameter through which an electric shock could be delivered. The presentation of stimuli was controlled automatically and could be adjusted so that either the buzzer or the shock came first. The latencies of wheel rotation after buzzer and after shock were measured separately on two electric timers and the number of wheel rotations was recorded on a counter to the nearest one-fourth revolution. A wax-paper polygraph was also used to record the buzzer, the shock, and each one-fourth revolution of the wheel.[3]

[3] All measurements of wheel rotations were recorded in quarters of a wheel rotation, but the final results are presented in terms of complete wheel rotations by dividing by four.

Procedure

Preliminary training.—All *S*s were first trained to escape the shock promptly by turning the wheel as soon as the grid was electrified. On the first day *S* was placed in the experimental apparatus and after 2 min. an electric shock was delivered from the grid and could be escaped by turning the wheel. Subsequent trials were given, separated by intervals of 60 and 90 sec. alternately. The same procedure continued until *S* responded to the shock on ten successive trials with a latency less than 1 sec. After reaching this criterion, which was attained by most *S*s in less than 40 trials, *S* was returned to his living cage. After a 23-hr. rest, *S* was placed again in the apparatus and was given the same training to the same criterion. Rats that did not reach the criterion within 40 trials on the second day were discarded.

Conditioning to the buzzer.—Conditioning started on the third day by sounding a loud buzzer for 2 sec. followed by an electric shock. Both buzzer and shock stayed on together until the rat rotated the wheel, which turned off both of them at the same time. If *S* rotated the wheel to the sound of the buzzer within 2 sec., the buzzer stopped immediately and no shock was delivered. Intervals between trials were 60 and 90 sec. alternately to avoid conditioning the rats to a particular duration of time.

Conditioning trials continued until the *S*s reached a criterion of ten consecutive responses to the buzzer alone. A rest interval of 10 min. during which *S* was removed from the apparatus was introduced after the fiftieth conditioning trial if *S* had not already reached the criterion of conditioning. The *S*s differed in the number of trials required to reach this criterion, but in no case was more than 100 trials required.

After reaching the conditioning criterion, a 5-min. rest was given during which *S* was removed from the experimental apparatus. Then experimental trials began.

Three experimental procedures.—All *S*s received the same treatment under the same conditions during preliminary training and conditioning; then they were divided into three groups which were given the following different experimental treatments. During *all* experimental trials the shock *following* the buzzer was eliminated, i.e., there was no reinforcement immediately after the CS.

1. *Shock 1 sec. before buzzer.*—In order to test the effects of a reinforcement immediately preceding the CR, 12 *S*s were given 50 trials during which the buzzer followed 1 sec. after *S* had turned off the shock by starting to rotate the wheel.

2. *Shock 20 sec. before buzzer.*—In order to have a control for any general exciting or fatiguing effect of shock on the performance of the first group, 12 *S*s of a second group were given 50 trials during which they were always shocked 20 sec. before the buzzer (40 sec. after the buzzer of the preceding trial). The relatively long interval of 20 sec. before or 40 sec. after the buzzer would be expected to prevent the formation of any association between it and the shock, or at least to produce a much weaker one than the short interval of 1 sec.

3. *No shock (normal extinction).*—In order to determine what the effect of the shock between trials was on the rats in the preceding group, a third group of 12 *S*s was run with the procedure normally used in experimental extinction, i.e., they were given 50 trials with the buzzer without any shock.

Test under equivalent conditions.—In using the performance during the 50 trials involved in each of the foregoing procedures to compare the three groups, it is impossible to separate the immediate distracting or dynamogenic effects of the procedure (e.g., shock 1 sec. before buzzer) upon the performance of the CR during these trials from any more permanent learned after-effect of inhibition or reinforcement. In order to separate the effects on learning from those on immediate performance, it was necessary to test *S*s from each group under the same conditions. In order to have these test conditions involve the same amount of change (i.e., stimulus generalization) from the immediately preceding experimental procedures, each of the three groups was divided into three subgroups: one was given 50 additional trials under the first experimental procedure (shock 1 sec. before buzzer), one was given 50 trials with the second procedure (shock 20 sec. before buzzer), and one given 50 trials with the third procedure (no shock). This resulted in a total of nine subgroups.

The duration of the buzzer was always 2 sec. for all the groups during the whole 100 experimental and test trials. The interval between successive trials was always 60 sec. At the end of the 50 experimental trials the rats were given a 5-min. rest during which they were offered food and water for the purpose of calming them down before they were tested.

Control for fatigue.—In order to determine the effect of 100 shock trials on the performance level of the animals, a special control group of four rats, after having been conditioned in the same way as the experimental groups, was given 100 shock trials without buzzer and, immediately after that, ten extinction trials with buzzer alone.

Measurements of CR's.—Two measurements were obtained, the *frequency* and the *amplitude* of the CR's. In these measures a correction was made in those cases (particularly when shock was given 1 sec. before the buzzer) when the rats were already rotating the wheel before the onset of the buzzer by discounting the first one-fourth revolution because that was probably momentum.[4] Any additional revolutions were counted as making a response. The number of additional revolutions (measured to the nearest one-fourth revolution) up to a pause of 2 sec. or more without wheel rotation was counted as the amplitude of the response.

Results and Discussion

Experimental trials.—Figure 1 shows the results of the three experimental groups in terms of amplitude of CR, Fig. 2 in terms of frequency. It is clear from these figures that both the amplitudes and the frequencies of CR's for all the three groups decreased during the 50 experimental trials, a phenomenon analogous to experimental extinction. To test for the reliability of these decrements the total scores of each *S* on Trials 41–50 were subtracted from those on Trials 1–10 and *t*-tests were made to see if the decrement for each group was significantly different from zero. The results are presented in Table I. It can be seen that the decrements in both frequency and amplitude were significant for all groups with the exception of the frequency scores for the group shocked 1 sec. before the buzzer.[5]

In contrast with the decrement shown by the experimental groups, it can be seen in Fig. 1 and 2 that the group given 100 trials with shock alone in place of the experimental and test procedures and then given ten trials with buzzer alone performed at approximately as high a level during

[4] Since the three experimental groups were tested under exactly the same sets of conditions, any inexactness in this correction will be balanced out in the comparisons between the groups.

[5] In this case the perseveration of the wheel rotation to the shock probably accounts for the lack of a statistically reliable decrease in frequency.

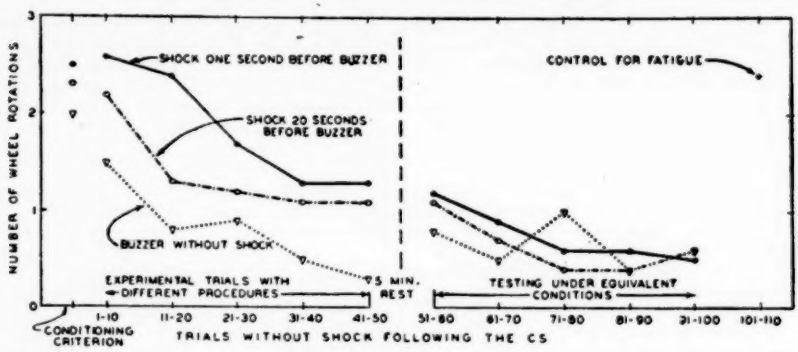

FIG. 1. The mean amplitude of CR's in the three experimental groups during experimental and test trials. The points at the extreme left indicate the mean number of wheel rotations to the buzzer alone during the ten criterion trials. Experimental trials started 5 min. after reaching the criterion. The group used as a control for fatigue was given 100 trials with shock alone followed by ten trials with buzzer alone.

these trials (101–110) as the other animals did at the beginning of the experimental series (trials 1–10). This would seem to indicate that fatigue from rotating the wheel was not a major factor in producing the decrement observed in the experimental groups.

It is clear from these results that the responses suffered extinction under each of the three experimental conditions used. The fact that the curve for the group with shock 1 sec. before the buzzer went down rather than up shows that the close association between the reinforcement from

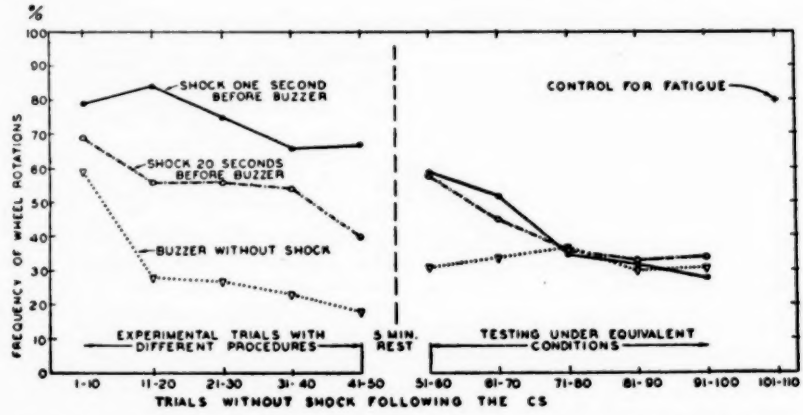

FIG. 2. The mean frequency of CR's in the three experimental groups during experimental and test trials. Experimental trials started 5 min. after reaching the criterion. The frequency of response on the ten criterion trials was necessarily 100 per cent for all groups. The group used as a control for fatigue was given 100 trials with shock alone followed by ten trials with buzzer alone.

TABLE I

p-VALUES OF DIFFERENCES BETWEEN ZERO AND DECREMENTS IN RESPONSE STRENGTH FROM TRIALS 1–10 TO TRIALS 41–50

Measure	Condition		
	Shock 1 Sec. before CS	Shock 20 Sec. before CS	CS without Shock
Amplitude	.01	<.05	<.01
Frequency	>.20	.001	<.01

the shock and the subsequent response to the buzzer did not strengthen the connection between the buzzer and wheel rotation as would be expected from the principles of "a bi-directional spread of effect" or "backward conditioning."

Although the trend in all three groups is downward, it can be seen from Fig. 1 and 2 that there are differences in the general levels of the curves. In both frequency and amplitude the curve for the group with shock 1 sec. before the buzzer is above that for the group with shock 20 sec. before the buzzer, which in turn is above that for the group with no shock. (Similar differences, which must have been produced by chance in the selection of the *S*s, are also present among the mean amplitudes of the three groups during the ten criterion trials; these differences are not statistically reliable.) In order to test the reliability of the differences among the groups during the first 50 experimental trials, the scores (for frequency or amplitude respectively) of each *S* on all 50 trials were summed and an analysis of variance was made of these scores. For both frequency and amplitude the *F*-test was significant well beyond the .01 level. Then *t*-tests were made for the differences among the separate groups. As can be seen from Table II all of these differences were significant except the difference in frequency between the groups with shock 1 sec. and 20 sec. before the buzzer.

These differences in level of performance of the groups during the first 50 experimental trials could easily have been produced by fear perseverating from the shock. If there was a general perseveration of fear, it would raise the level of drive and hence of performance. In other words, the differences in the general level of performance of the three groups might be a transitory, dynamogenic effect of the shock on immediate performance rather than any more permanent learned effect of reinforcement.

Tests under equivalent conditions.—In the tests under equivalent conditions the more permanent specific effects (inhibition or reinforcement) on learning are separated from any general dynamogenic effects of the different procedures on immediate performance. Any specific effect of the close association between shock and buzzer would be expected to show up in the comparison between the 1-sec. and 20-sec. groups. As can be seen, there is very little difference in either the frequency or amplitude

TABLE II

p-VALUES OF DIFFERENCES BETWEEN GROUPS IN RESPONSE STRENGTH ON THE FIRST 50 EXPERIMENTAL TRIALS

Condition	Shock 20 Sec. before CS	CS without Shock
	Amplitude	
Shock 1 sec. before CS	<.05	<.001
Shock 20 sec. before CS		<.02
	Frequency	
Shock 1 sec. before CS	>.10	<.001
Shock 20 sec. before CS		<.05

scores of these two groups.[6] Analyses of variance of the sums of the first ten test trials revealed that the experimental conditions and the test conditions were significant sources of variance ($p = .05$ and .01, respectively) in the frequency scores, but not in the amplitude scores. t-tests were made separately for the sum of the first ten test trials and the resulting p-values are shown in Table III. This analysis was repeated for the sums of all 50 test trials.

In neither case did the differences between the 1-sec. and the 20-sec. groups approach statistical reliability.[7] The similar performance of these two groups during the test trials indicates clearly that the direct association between the shock on the one hand and the immediately subsequent buzzer and avoidance response on the other does not have any marked effect on that response: it does not strengthen the response or even reliably retard extinction, nor does it hasten extinction. The shock as a reinforcing event has little if any specific effect on the closely following S-R connection.

There is, however, some evidence for a general after-effect of the shocks given during the preceding experimental trials. It can be seen that during the first ten test trials (51–60 in Fig. 1 and 2) the scores of both groups that had received shock during the preceding experimental trials are higher in terms of both frequency and amplitude than those of the *S*s that had received no shock. Table III shows that for the frequency scores

TABLE III

p-VALUES OF DIFFERENCES BETWEEN GROUPS IN FREQUENCY OF RESPONSE ON THE FIRST TEN TEST TRIALS AS A FUNCTION OF EXPERIMENTAL CONDITIONS AND TEST CONDITIONS

Condition	Shock 20 Sec. before CS	CS without Shock
	Test Conditions	
Shock 1 sec. before CS	>.05	<.001
Shock 20 sec. before CS		>.05
	Experimental Conditions	
Shock 1 sec. before CS	>.80	<.02
Shock 20 sec. before CS		<.05

the difference between each of the shock groups and the non-shock group is reliable. This indicates the persistence of a general facilitating effect of the shock. This effect is analogous to pseudo-conditioning in that it does not vary with the closeness of association between the shock and the CS as shown by the lack of difference between the 1-sec. and 20-sec. groups. It seems probable that this general facilitation is produced by fear conditioned to the cues in the apparatus and operating to increase the general level of drive and hence of performance (**17**).

It is also clear from Fig. 1 and 2 that the curves for the group that had received the preceding trials without shock showed an increase during test trials when shock was introduced. When the three subgroups involved in this group were examined separately it was obvious that all of the increase was contributed by the two subgroups for whom the final testing procedure involved the introduction of shock either 1 sec. or 20 sec. before the buzzer. The fact that introducing the shock without any close association with the buzzer (the 20-sec. subgroup)

[6] Furthermore, it can be seen that the trend of extinction that occurred during the experimental trials continued during the test trials. Each of the three subgroups involved in each of these two main groups showed this same downward trend.

[7] See the effects of experimental conditions in Table III.

produced an increase which is not reliably different from the increase in the 1-sec. subgroup further suggests that the increase was produced by a rise in the general level of fear rather than by any specific reinforcing effect depending on a close association between the shock and the buzzer.

Summary and Conclusions

Forty albino rats were conditioned to rotate a wheel to the sound of a buzzer, and then were given 50 experimental trials under three different conditions: (a) shock 1 sec. before the buzzer; (b) shock 20 sec. before the buzzer; and (c) the buzzer alone without shock. In order to have a control for the effect of fatigue on performance, a special control group of four rats, after having been conditioned in the same way, was given 100 shock trials and then was given 10 trials with buzzer alone. Each of the three major groups was divided into three subgroups which were given an additional 50 trials under the three major conditions. The results and conclusions of the present experiment are as follows:

1. The net effect of applying shock 1 sec. before the conditioned avoidance response to the buzzer is to produce a decrement in the strength of the avoidance response rather than to produce any increment as might be expected from "backward conditioning" or a "spread" of reinforcement to subsequent events. These results support Pavlov's report that applying the UCS before the CS produces extinction of the CR.

2. The amount of this extinction is not reliably different from that observed in the control group with a shock 20 sec. before the buzzer. Thus in addition to being unable to prevent extinction, the association between the shock and the conditioned avoidance response following it seems to have been unable even to slow down extinction. It does not, however, seem to speed up extinction. The close association (1 sec.) between the reinforcement of shock and the following conditioned avoidance response to the buzzer seems to have been without any effect.

3. There is some evidence that the presence of shock during extinction trials, irrespective of whether it closely preceded the conditioned avoidance response or not, had a general facilitating effect on this response analogous to that of pseudo-conditioning. It seems reasonable to conclude that this effect was produced by increasing the general level of fear as a drive during the test trials.

(Manuscript received November 2, 1950)

References

1. Bernstein, A. L. Temporal factors in the formation of conditioned eyelid reactions in human subjects. *J. gen. Psychol.*, 1934, **10**, 173–197.
2. Brandt, H. The spread of the influence of reward to bonds remote in sequence and time. *Arch. Psychol.*, N. Y., 1935, **27**, No. 180.
3. Brown, J. S. A note on a temporal gradient of reinforcement. *J. exp. Psychol.*, 1939, **25**, 221–227.
4. Carr, H. A., and Freeman, A. S. Time relations in the formation of associations. *Psychol. Rev.*, 1919, **26**, 465–473.
5. Cason, H. The conditioned eyelid reaction. *J. exp. Psychol.*, 1922, **5**, 153–196.
6. Cason, H. Backward conditioned eyelid reactions. *J. exp. Psychol.*, 1935, **18**, 599–611.
7. Farber, I. Spread of effect of reward and punishment in a multiple choice situation. *Proc. Iowa Acad. Sci.*, 1941, **48**, 313–317.
8. Grant, D. A. The pseudo-conditioned eyelid response. *J. exp. Psychol.*, 1943, **32**, 139–149.
9. Grether, W. F. Pseudo-conditioning without paired stimulation encountered in

attempted backward conditioning. *J. comp. Psychol.*, 1938, **25**, 91–96.

10. HARLOW, H. F. Forward conditioning, backward conditioning, and pseudo-conditioning in the goldfish. *J. genet. Psychol.*, 1939, **55**, 49–58.
11. HARRIS, J. D. Forward conditioning, backward conditioning, pseudo-conditioning, and adaptation to the conditioned stimulus. *J. exp. Psychol.*, 1941, **28**, 491–502.
12. JENKINS, W. O. Studies in the spread of effect. *J. comp. Psychol.*, 1943, **35**, 41–72.
13. JENKINS, W. O., AND SHEFFIELD, F. D. Rehearsal and guessing habits as sources of the "spread of effect." *J. exp. Psychol.*, 1946, **36**, 316–330.
14. LEPLEY, W. M. A gradient in incidental learning. *J. exp. Psychol.*, 1935, **18**, 195–201.
15. MARTENS, D. Spread of effect in verbal serial learning. *Amer. Psychologist*, 1946, **1**, 448–449. (Abstract.)
16. MAY, M. A. An interpretation of pseudo-conditioning. *Psychol. Rev.*, 1949, **56**, 177–183.
17. MILLER, N. E. Studies of fear as an acquirable drive: I. Fear as motivation and fear-reduction as reinforcement in learning of new responses. *J. exp. Psychol.*, 1948, **38**, 89–101.
18. MUENZINGER, K. F., AND DOVE, C. C. Serial learning: I. Gradients of uniformity and variability produced by success and failure of single responses. *J. gen. Psychol.*, 1937, **16**, 403–413.
19. MUENZINGER, K. F., DOVE, C. C., AND BERNSTONE, A. H. Serial learning: II. The bi-directional goal gradient in the endless maze. *J. genet. Psychol.*, 1937, **50**, 229–241.
20. NAGATY, M. O. The effect of reinforcement on closely following S-R connections: II. The effect of a food reward immediately preceding the performance of an instrumental conditioned response on the extinction of that response. *J. exp. Psychol.* (In press.)
21. NUTTIN, J. "Spread" in recalling failure and success. *J. exp. Psychol.*, 1949, **39**, 690–699.
22. PAVLOV, I. P. *Conditioned reflexes.* (Translated by G. V. Anrep.) London: Oxford Univ. Press, 1927.
23. PAVLOV, I. P. *Lectures on conditioned reflexes.* (Translated by W. H. Gantt.) New York: International, 1928.
24. PORTER, J. M. Backward conditioning of the eyelid response. *J. exp. Psychol.*, 1938, **23**, 403–410.
25. SHEFFIELD, F. D. "Spread of effect" without reward or learning. *J. exp. Psychol.*, 1949, **39**, 575–579.
26. SMITH, M. H., JR. Spread of effect is the spurious result of non-random response tendencies. *J. exp. Psychol.*, 1949, **39**, 355–368.
27. SPOONER, A., AND KELLOGG, W. N. The backward conditioning curve. *Amer. J. Psychol.*, 1947, **60**, 321–335.
28. SWITZER, S. A. Backward conditioning of the lid reflex. *J. exp. Psychol.*, 1930, **13**, 76–97.
29. TAYLOR, D. W. Spread of effect in one-trial learning in relation to the guessing-sequence hypothesis. *Amer. Psychologist*, 1947, **2**, 313. (Abstract.)
30. THOMPSON, M. E., AND DOVE, C. C. A further study on the bi-directional goal gradient in the endless maze. *J. exp. Psychol.*, 1943, **33**, 447–456.
31. THORNDIKE, E. L. A proof of the law of effect. *Science*, 1933, **77**, 173–175.
32. THORNDIKE, E. L. An experimental study of rewards. *Teach. Coll. Contr. Educ.*, 1933, No. 580.
33. TILTON, J. W. The effect of "right" and "wrong" upon the learning of nonsense syllables in multiple choice arrangement. *J. educ. Psychol.*, 1939, **30**, 95–115.
34. TILTON, J. W. Gradients of effect. *J. genet. Psychol.*, 1945, **66**, 3–19.
35. WALLACH, H., AND HENLE, M. An experimental analysis of the law of effect. *J. exp. Psychol.*, 1941, **28**, 340–349.
36. WALLACH, H., AND HENLE, M. A further study of the function of reward. *J. exp. Psychol.*, 1942, **30**, 147–160.
37. WOLFLE, H. M. Time factors in conditioning finger withdrawal. *J. gen. Psychol.*, 1930, **4**, 372–378.
38. WOLFLE, H. M. Conditioning as a function of the interval between the conditioned and the original stimulus. *J. gen. Psychol.*, 1932, **7**, 80–103.
39. YARBOROUGH, J. U. The influence of the time interval upon the rate of learning in the white rat. *Psychol. Monogr.*, 1922, **30**, No. 135.
40. ZIRKLE, G. A. Success and failure in serial learning: II. Isolation and the Thorndike effect. *J. exp. Psychol.*, 1946, **36**, 302–315.

LATENCY AND DURATION OF MONOCULAR AND BINOCULAR AFTER-IMAGES

BY HENRYK MISIAK AND CARL C. LOZITO

Fordham University

The problem of monocular versus binocular visual functions is a problem of long standing. Greatest interest has been in stereopsis and its psychologic and physiologic components, but the question of whether such functions as acuity and brightness discrimination are improved when two eyes are used has been extensively investigated. Fechner's paradox is a problem that must be considered in this connection, and problems of interaction of brightnesses are of considerable importance.

The evidence on the question of binocular summation of brightnesses is conflicting. Duke-Elder (**5**), making a survey of studies, states that no dogmatic opinion about summation should be given. He is inclined to doubt the occurrence of binocular summation, and ascribes summation allegedly found by some workers to the faulty techniques employed. This attitude, which we can also find in many other authors, is due, at least partly, to the prestige of Sherrington who, in view of the results of his flicker and fusion experiments, rejected binocular summation. Other workers could not be reconciled to the rejection of binocular interaction and summation (**1, 4, 7, 11**).

The present investigation is concerned with the latency and duration of negative after-images as observed monocularly and binocularly. Creed and Harding (**4**) found that binocular after-images had the same latency as monocular after-images when projected on a white surface but appeared earlier when projected on a black surface. Differences in quality between the binocular and monocular after-images also appeared. As an explanation of their results they postulated interaction between the retinocerebral mechanisms of the two eyes, placing it tentatively "at a subperceptual level in the brain" (**4**, p. 439). It seemed worthwhile to obtain more information about the after-images, e.g., measuring their latencies and durations under various conditions with refined techniques and with a large number of *S*s.

Procedure

The *S*s were 20 white men with normal color and stereoptic vision; in some cases acuity had been corrected by glasses. Their age range was from 18 to 40 years with a mean of 25.5.

The apparatus consisted of electrical timers regulating the exposure time, two chronoscopes (Standard Electric Time Co., Model S-1) measuring the latency and duration of the after-images, and a separate viewing chamber. The latter was an elongated box with a light source (7.5-w. bulb) illuminating filters in a panel at one end, and an eyepiece at the other end. Two Wratten 2 × 2 in. gelatin filters, red and green (Kodak A-25 and ×2–13), in the shape of a cross, inserted in the panel of the box served as the exposure field. A flash-opal glass, also 2 × 2 in., placed below the exposure field, served as the after-field. A special separation in the box made possible binocular or monocular observation of the fields. The intensity of exposure fields, both green and red, was 5 foot-candles. The after-field was white light of 15 foot-candles.

The *S*s were kept in darkness for 10 min. before the experiment. The stimulus was presented to them for 30 sec., immediately after which the after-field was illuminated and at the same time a chronoscope was started to register the time. All of these events were controlled automatically by electric timers. With the appearance of the after-image on the after-field, *S*

pressed a key which stopped the first chronoscope and started another one. When the after-image disappeared, i.e., when the shape of the cross faded away, *S* released the key and the second chronoscope stopped. The *E* then recorded the time in .01 sec. shown by the two chronoscopes, the first giving the latency, and the second the duration of the after-image.

Each *S* was tested on two days. In each session he received 16 stimulations, eight of which were with red filters, and eight with green filters. Of each group of eight stimulations, four were monocular (right and left eyes) and four binocular. The sequence was such as to eliminate any influence of practice, position, etc. All after-images were negative and of complementary colors.

Results

The main results are shown in Table I. There were no significant changes in latency or duration from day to day or from red to green color.

TABLE I

Latency and Duration (in Seconds) of Monocular and Binocular After-Images

Measure	Monocular		Binocular		t	r
	Mean	*SD*	Mean	*SD*		
Latency	1.02	0.43	0.87	0.29	3.62	.89
Duration	2.19	0.73	2.86	1.20	3.81	.70

Binocular after-images had about a 15 per cent shorter latency, and about a 24 per cent longer duration than the monocular after-images.

The results of our experiment, although obtained under quite different conditions, corroborate the results of Creed and Harding (**4**) with respect to the shortened latency of binocular after-images. We are also in agreement with results of a more recent study by Cooper (**3**).

Discussion

The shorter latency and greater duration of binocular after-images are difficult to explain in terms of peripheral factors. The peripheral factors which Horowitz (**6**) considered for the explanation of binocular superiority in acuity are hardly applicable to such a phenomenon as the after-image. It seems more plausible to apply Creed and Harding's postulation of interaction between the two retino-cerebral apparatuses of the eyes.

Apparently, the sensory and neural processes of each eye in after-images are reinforcing each other and thus enhancing the total effect of the stimulation. Psychologically speaking, we should then assume that the stimulus appears brighter under binocular stimulation. Brightness enhancement would explain binocular superiority of other visual functions as reported by other investigators who, studying monocular-binocular differences, found that under binocular stimulation, at least for their experimental conditions, reaction time was shorter (**2, 10**), visual threshold lower (**8**), critical flicker frequency higher (**7, 9**), pupillary light reflex greater (**11**), and brightness of the stimulus increased (**1**). The mutual reinforcement of the two eyes, leading in consequence to the summation effect, is probably not equal for all the degrees of intensity of light. We can expect the existence of some optimal intensity for summation. In differential stimulation of both eyes we may encounter optimal conditions for the opposite effect, i.e., subtraction, as in Fechner's paradox. These conditions, however, have not yet been systematically explored. In any event, either of these two effects cannot be reconciled with the idea of independent mechanisms of each eye, both actually postulating the existence of interaction between visual impulses coming from each eye simultaneously. The place of this inter-

action, subcortical or cortical, or both, can be at present only a matter of speculation. Our results, moreover, support the view that the after-image is not only a peripherally determined affair, but also is subject to central modification.

Summary

Latency and duration of monocular and binocular after-images of 20 male *Ss* were measured and compared. The latency of binocular after-images was significantly shorter and the duration longer. This result suggests the existence of interaction between the mechanisms of the two eyes.

(Manuscript received
November 10, 1950)

References

1. Bartley, S. H. *Vision.* New York: Van Nostrand, 1941.
2. Begley, M. J. A comparative study of reaction times under conditions of binocular and monocular stimulation. Unpublished Master's thesis, Fordham Univ., 1949.
3. Cooper, J. B. Some characteristics of negative after-images. *J. gen. Psychol.*, 1948, **39**, 217–228.
4. Creed, R. S., and Harding, R. D. Latency of after-images and interaction of the two retino-cerebral apparatuses in man. *J. Physiol.*, 1930, **69**, 423–441.
5. Duke-Elder, W. S. *Text-book of ophthalmology.* St. Louis: C. V. Mosby, 1946.
6. Horowitz, M. W. An analysis of the superiority of binocular over monocular visual acuity. *J. exp. Psychol.*, 1949, **39**, 581–596.
7. Ireland, F. H. A comparison of critical flicker frequencies under conditions of monocular and binocular stimulation. *J. exp. Psychol.*, 1950, **40**, 282–286.
8. Lythgoe, R. J., and Phillips, L. R. Binocular summation during dark adaptation. *J. Physiol.*, 1938, **91**, 427–436.
9. Misiak, H. Age and sex differences in critical flicker frequency. *J. exp. Psychol.*, 1947, **37**, 318–332.
10. Poffenberger, A. T. Reaction time to retinal stimulation with special reference to the time lost in conduction through nerve centers. *Arch. Psychol., N. Y.*, 1912, No. 23.
11. Thomson, L. C. Binocular summation within the nervous pathways of the pupillary light reflex. *J. Physiol.*, 1947, **106**, 59–65.

WARM-UP EFFECT AS A FUNCTION OF LEVEL OF PRACTICE IN VERBAL LEARNING[1]

BY LELAND E. THUNE

Vanderbilt University

Recent studies have called attention to the role of a warm-up factor in verbal learning and retention (**1, 3, 4, 7**). Although each of these studies concerned itself with a unique problem, they all effectively demonstrated the presence and significance of a warm-up factor in paired-associate verbal learning with relatively unpracticed *Ss*. The primary aim of the present investigation is to determine the degree to which this warm-up factor operates in the performance of more highly practiced *Ss* in a similar verbal learning situation.

Only two studies have reported data on the relative rates with which comparable word lists (or other verbal materials) are learned under conditions which permit a separation of those transitory effects of practice which we call *warm-up* from the more stable *general practice* or learning-to-learn effects which carry over from one session to another. In 1928 Heron (**2**) reported a study in which he claimed to have found a significant warm-up effect in a verbal learning experiment which involved the learning of two related paired-associate lists on each of three days. The first list on the second experimental day required significantly more trials to learn than did the second list learned on the first day. Similarly, the first list learned on the third day was learned less rapidly than was the second list on either of the two preceding days.

Heron's conclusions regarding the presence of a valid warm-up effect have been questioned by Mitchell (**6**) on the basis that the four sessions which were employed were separated by such a long time interval (one week) that the general practice effect from one session was lost (forgotten) before the next. Mitchell then reports some pertinent data gathered incidentally while the author was investigating another problem. Although there were minor variations in experimental procedure for some *Ss*, the general design of the experiment has been stated as follows: "The subjects learned at least two lists of 10 3-place numbers per day, five to six days per week for from 16 to 84 days . . ." (**6**, p. 139). Neither errors nor trials to reach one perfect repetition revealed any significant difference in the mean rate with which those lists which came first and those which came second were learned. Further, there was no tendency for the relative rate with which the second list was learned with respect to the first, to change with increasing days of practice.

It is possible that Mitchell's failure to obtain evidence for a warm-up effect arose because the design of her experiment, including the methods and materials employed, tended to suppress the appearance of such a factor. Thus, performance on the second list each day may have been influenced by proactive inhibition from the first list. This inhibitory factor may have been enough to offset any warm-up facilitation which might

[1] This research was supported in part by funds made available jointly by the Carnegie Foundation and Vanderbilt University.

otherwise have occurred. This interpretation becomes all the more plausible when one considers the fact that Mitchell's *Ss* learned serial lists of 3-digit numbers with only a 45-sec. or a 2-min. rest interval between successive lists. The opportunities for proactive inhibition of the second list are large under these conditions. On the other hand, because of the relatively long (about 24-hr.) time interval between it and the previous list, the first list learned on each day may have been subject to only small amounts of proactive inhibition.

The present experiment may be regarded as an extension and refinement of the earlier work of Heron and Mitchell. The conditions have been arranged so as to permit the general practice and the warm-up effects to reveal themselves unambiguously. Further, it is possible to determine the form of the functional relationship existing between the warm-up effect and the *S*'s level of practice.

Method

Procedure.—All *Ss* served under the same experimental conditions. Fifteen lists of paired adjectives were learned, three lists being learned successively on each of five days. Each list was presented for a minimum of ten trials. If *S* had not reached the criterion of one perfect repetition by the end of the tenth trial, additional trials were given until this criterion was attained. A 12-min. rest interval was interpolated between the successive lists learned within each day. During this interval *E* changed the list of words on the memory drum and engaged *S* in conversation irrelevant to the experiment.

Because of conflicts with week-end holidays and individual class schedules, it was not always possible to arrange for the five experimental sessions to come on successive days. Of the 240 inter-session intervals (four for each of 60 *Ss*) 65 per cent involved a one day interval, and 18, 13, 3 and 1 per cent involved intervals of 2, 3, 4 and 5 days, respectively. Inter-session intervals which exceeded one day tended to distribute themselves evenly throughout the four inter-session intervals.

Apparatus and materials.—All lists were presented on a modified Hull-type memory drum. The apparatus was mounted on a table in such a manner that the front of the drum projected through an opening in a plywood screen which served to shield *E* from *S* and to minimize the number of distractions to which *S* would be subjected. The stimulus word of each pair was presented for 4 sec., the stimulus and response words being jointly exposed during the last 2 sec. of this interval.

Each list was composed of ten pairs of two-syllable adjectives. The lists were made as homogeneous as possible. Formal associations between stimulus and response words within a single list and between the various lists were minimized. Five different serial orders of presentation were employed for each list. There was an 8-sec. rest interval between trials within a list. During this interval the drum continued to turn but only blank spaces appeared in the exposure window.

Although each *S* learned only 15 lists, 17 word lists were employed.[3] Which 15 out of the 17 lists would be learned, and the particular order in which they would be learned, was determined separately for each *S* through the use of a table of random numbers.

Subjects.—Sixty undergraduate students (44 men and 16 women) enrolled in psychology courses served as volunteer *Ss*. None had had previous experience in a memory drum experiment, and all were naive with respect to the purpose of the experiment. The topic of warm-up had not been discussed in any of their classes.

At the time of their first session, a set of written instructions was read to each *S*. No further instructions were given other than to say, "Now learn this list as rapidly as you can," just before each new list was presented. Since this study was primarily concerned with intra-day and inter-day practice effects, no preliminary practice lists were employed.

Results and Discussion

The present experiment investigated rate of paired-associate verbal learning as a function of (a) the

[3] A total of 17 lists was employed because these same *Ss* returned for a sixth experimental session during which they learned two additional lists. The activity on the sixth day constituted a separate study and will be reported at a later time. However, it was important that the lists learned on the sixth day be comparable with those learned on the first five days reported in the present study, hence all 17 lists were randomized together.

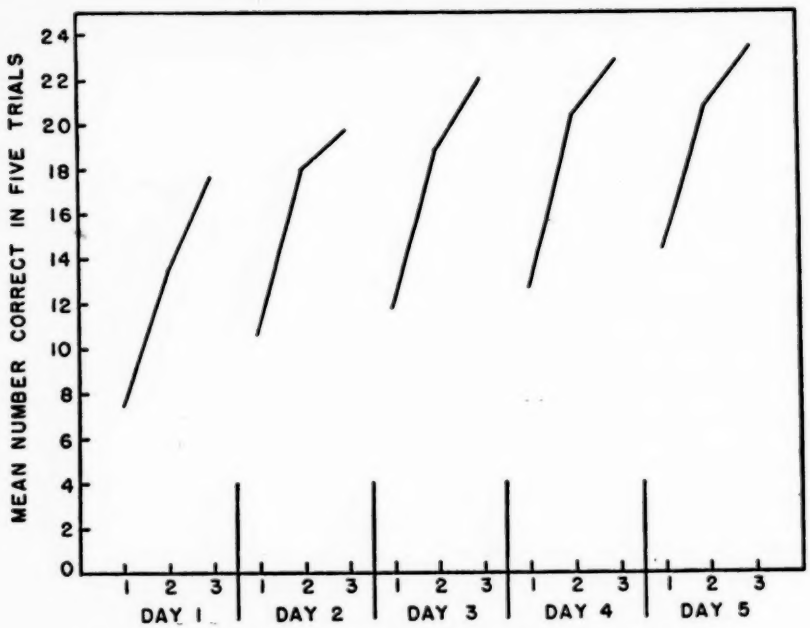

FIG. 1. Mean total number of correct anticipations on the first five trials for each of the three lists learned on each of the five days ($N = 60$)

amount of prior practice received within a single session (e.g., position within a session), and (b) the overall amount of prior practice received on previous sessions (e.g., session number within the series). The following three measures of performance were employed in the analysis of the data from the learning of each list: (a) the number of correct anticipations on the first five trials, (b) the number of correct anticipations on the first ten trials, and (c) the number of trials required to reach the criterion of one perfect repetition. Figure 1 shows how performance measured by the mean correct anticipations on the first five trials, varied as a function of position within a session and of the session number within the series. The mean number of trials required to reach one perfect repetition on each of the three lists on each of the five days is given in Table I. Data based upon the mean number of correct anticipations on the first ten trials are not included here since this performance measure correlated highly with each of the other two, and since a graphical plot of these data yielded a set of curves almost identical with those shown in Fig. 1.[3]

The group data were subjected to an analysis of variance and the *F*-test applied to evaluate the significance

[3] Means and *SD*'s of the number of correct anticipations on the first five trials and the first 10 trials may be obtained by ordering document 3405 from the American Documentation Institute, 1719 N Street, N. W., Washington 6, D. C., remitting $1.00 for 35 mm. microfilm or $1.00 for 6 × 8 in. photocopies.

of the within-sessions and between-sessions differences and of the interaction effect between position-within-a-session and session-number-within-the-series. The *F*-tests for within-sessions and between-sessions gains were significant at beyond the .001 level for all three performance measures. (For within-sessions, $F = 155.73$ for mean number correct in five trials, 251.96 for mean correct in ten trials, and 139.48 for trials to reach one perfect repetition, with 2 and 885 *df* in each case; for between-sessions, the corresponding *F*-ratios were 24.16, 32.19, and 18.78, with 4 and 885 *df*.) The interaction variance between position-within-a-session and session-number-within-the-series lacked statistical significance when tested on the basis of the total number of correct responses on the first five trials, and the number of trials required to reach one perfect repetition. ($F = .24$ for mean correct in five trials and 1.10 for mean trials to reach one perfect repetition, with 8 and 885 *df*.) When performance was evaluated in terms of the number of correct responses in the first ten trials, this interaction test yielded an *F*-ratio of 2.34 which was significant at between the .01 and .05 levels of confidence for the 8 and 885 *df* involved.

The rate with which individual lists were learned was undoubtedly influenced by a multiplicity of psychological factors. Within the framework of the present experiment, some of the more important of these factors may have been: (a) Facilitation of performance on successive lists within and between sessions due to general practice or learning-to-learn effects. (b) Facilitation of performance on successive lists within each session due to warm-up effects. (c) Possible interaction between the general practice effect and the warm-up effect. (d) Inhibition of performance due to proactive inhibition from lists learned previously within that same session and perhaps from earlier sessions.

Numerous studies, such as those of Ward (**8**) and of Melton and von Lackum (**5**), have reported a negatively accelerated relationship between rate of learning and general level of practice. Successive gains due to general practice effects tend to be largest during the early stages of practice and thereafter become progressively smaller. Presumably, in the present experiment, performance on all lists (both within and between

TABLE I

MEAN TRIALS REQUIRED TO THE CRITERION OF ONE PERFECT REPETITION FOR LISTS LEARNED IN EACH OF THREE POSITIONS ON EACH OF FIVE DAYS ($N = 60$)

Position within Session	Learning Session										All Sessions	
	Day 1		Day 2		Day 3		Day 4		Day 5			
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
List 1	21.62	9.63	17.98	8.11	17.15	9.99	15.23	6.73	14.17	7.15	17.23	8.82
List 2	13.70	5.99	10.73	4.74	9.78	4.17	9.93	5.15	9.10	4.02	10.65	5.08
List 3	11.20	6.62	9.87	4.50	9.10	4.67	7.97	3.33	7.42	2.89	9.11	4.99
All positions	15.51	8.99	12.86	7.03	12.01	7.72	11.04	6.09	10.23	5.78	12.33	7.44

sessions) was influenced by this general practice effect. Although this effect influenced successive lists within each session, it is shown most clearly by the general rise in performance efficiency on corresponding lists learned on successive days. The presence of a general practice effect is statistically demonstrated by the significant *F*-ratios obtained when the between-sessions differences were tested by the analyses of variance reported above.

It is obvious that only a small part of the total within-sessions gains on individual days can be attributed to general practice or learning-to-learn effects. The remainder is ascribed to the warm-up effect since it was lost during the interval, usually 24 hrs., which separated the individual learning sessions. Although the greatest gain in rate of learning within individual sessions occurred between performance on the first and second lists, in each case sizable gains continued to take place between the second and third lists. Apparently an efficient or optimal state of warm-up is not attained with small amounts of practice within an individual session.

The relative magnitudes of the warm-up effect and of the general practice or learning-to-learn effect are indicated by the fact that for two out of the three measures of performance employed (number correct in ten trials and number of trials to reach one perfect repetition), the first list learned on the fifth day was mastered *less* rapidly than was the second list learned on the very first day.

The analyses of variance reported above suggest the possibility of there being a real interaction between position-within-a-session and session-number-within-the-series in determining level of performance on individual lists. At least part of this tendency can be accounted for on the basis of the negatively accelerated relationship between rate of learning and general level of practice. General level of practice was increasing during or within each session, although its effects are most readily observed by noting the change in performance efficiency on corresponding lists from one session to the next. The gain in efficiency on successive lists due to general practice or learning-to-learn effects was greatest at the lower levels of practice and became progressively less with the learning of each additional list. Thus a larger proportion of the increase in learning efficiency noted within the early sessions must be attributed to general practice effects, and hence less to warm-up effect, than for the later sessions. If, in interpreting the above data, allowance is made for the decreasing within-sessions gains attributable to general practice we see that the magnitude of the warm-up effect bears little relation to the *S*'s total level of practice.

It is evident from the data already presented that facilitation from general practice effects and from within-sessions warm-up greatly outweighed any proactive inhibitory effects which may have been built up from practice on previously learned lists. To the extent that inhibition was present, it would have tended to suppress the appearance of the warm-up effect and, to a lesser extent, the general practice effect. It is not possible to determine the absolute strengths of these opposing facilitory and inhibitory influences.

The only direct evidence for proactive inhibition comes from inter-list intrusion data. The total number of intrusions from prior lists was small. A total of only 38 inter-list intrusions obtained from the 60 *S*s each of whom learned 15 lists for an average of 12.3 trials. Of the 18 *S*s who gave any intrusions, 4 gave 1 intrusion each, 9 gave 2 intrusions, 4 gave 3 in-

trusions, and 1 *S* gave a total of 4 intrusions. Of the total of 38 intrusions, 5 occurred during the learning of a list that came first on its day, 16 occurred in a second list, and 17 occurred in a third list. The tendency to carry over a response from a previous session bore no relationship to the amount of prior learning on that particular day. As would be expected, intrusions occurring during the learning of the second and third lists each day were most likely to come from lists learned earlier on that same day than from lists learned on previous days. Approximately the same number of inter-list intrusions occurred on each of the five days. Thus, it appears that on later days, after the *S*s learned numerous lists on previous sessions (and thus could be expected to have a larger number of interfering associations from prior lists), they were better able to isolate the list being learned from prior lists. It is perhaps worth noting that the smallest number of intrusions (five) occurred on the fifth day, the day on which there were the greatest number of potentially competing responses.

Spontaneous comments given by *S*s suggest that, although they recognized that the first list each day tended to require more trials than the second, and particularly the third list, they attributed this greater difficulty to something about *the lists themselves*. It was not uncommon to receive comments such as: "The words in the first list are always a whole lot harder to associate than those on the other lists," or, "I wish that all of the lists were as short as the one I learn last each day."

Warm-up effects are not something that involve only the naive or unpracticed learner. The warm-up effect was almost as prominent on the fifth day of practice as on the first. Evidently, *S*s do not learn to overcome the handicap of lack of warm-up through self-instructions and self-induced sets. Had this been possible we might have expected that the within-sessions gains in learning efficiency would occur at progressively earlier stages *within* successive sessions. From inspection of Fig. 1 and Table I, this was not the case. With increasing days of practice, that portion of the within-sessions gains which took place between the first and second list did not become larger, relative to the gain from the second to the third list.

Other experiments (**4, 7**) have demonstrated that learning per se is not an essential aspect of those activities which serve to produce a favorable warm-up state in experiments such as this. Non-learning activities, such as color-guessing, carried out on a memory drum are virtually as effective as paired-associate or serial learning in producing a state of warm-up which aids performance in subsequent verbal learning tasks. On the other hand, cartoon-sorting, carried out at a desk within the same experimental room, has no facilitating warm-up effect (**7**).

As yet, we know very little about the fundamental nature of the warm-up state. Warm-up effects fall within the broad category of determiners of performance which we call *set*. However, the concept of set is so ill-defined and vague that it offers little as an explanatory principle. The warm-up state is most frequently thought of in terms of reinstatement of the postural and attentive adjustments necessary for optimal learning efficiency. It is suggested that one major aspect of this state may be readaptation to the rhythm of the apparatus and the establishment of a "readiness" set to make a response just as soon as the next stimulus appears. The factors which influence the establishment of this facilitating response set appear to be relatively independent of the *S*'s general level of practice.

Summary

1. Sixty undergraduate students, working individually and all serving under the same experimental condition, learned 15 10-item lists of unrelated paired-associate adjectives. Three different lists were learned to the criterion of one perfect repetition

on each of five days. A 2-min. rest interval was interpolated between the successive lists learned on each day.

2. The efficiency with which the various lists were learned was determined by two major variables: (a) the number of lists previously learned within that session, and (b) the number of prior learning sessions.

3. Within each session there was a marked rise in learning efficiency as shown by performance on successive lists. Most of this rapid intra-session gain was lost during the interval (generally one day) between sessions.

4. The warm-up gain which took place within each session was consistently larger than was the general practice effect obtained from all five sessions taken together.

5. Amount of intra-session warm-up gain was relatively independent of general level of practice as measured by the number of prior sessions.

(Manuscript received
November 16, 1950)

References

1. Hamilton, C. E. The relationship between length of interval separating two learning tasks and performance on the second task. *J. exp. Psychol.*, 1950, **40**, 613–621.
2. Heron, W. T. Warming-up effect in learning nonsense syllables. *J. genet. Psychol.*, 1929, **35**, 219–228.
3. Irion, A. L. The relation of "set" to retention. *Psychol. Rev.*, 1948, **55**, 336–341.
4. Irion, A. L. Retention and warming-up effects in paired-associate learning. *J. exp. Psychol.*, 1949, **39**, 669–675.
5. Melton, A. W., and von Lackum, W. J. Retroactive and proactive inhibition in retention: evidence for a two-factor theory of retroactive inhibition. *Amer. J. Psychol.*, 1941, **54**, 157–173.
6. Mitchell, M. B. The alleged warming-up effect in memorization. *J. exp. Psychol.*, 1933, **16**, 138–143.
7. Thune, L. E. The effect of different types of preliminary activities on subsequent learning of paired-associate material. *J. exp. Psychol.*, 1950, **40**, 423–438.
8. Ward, L. B. Reminiscence and rote learning. *Psychol. Monogr.*, 1937, **49**, No. 220.

THE EFFECT OF UNEQUAL AMOUNTS OF PRACTICE ON MOTOR LEARNING BEFORE AND AFTER REST[1]

BY CARL P. DUNCAN

Northwestern University

The superior performance achieved under distributed practice as compared to massed practice has now been frequently demonstrated in the field of motor learning. The empirical results appear clearly in, for example, the papers of Ammons (**1, 2**) and Kimble (**6, 7, 8, 9, 10**). With few exceptions, however, in the studies in which motor learning has been examined under both distributed practice (DP) and massed practice (MP), the actual amount of practice has been equal for both DP and MP. This means, of course, that the length of the experimental session was not equal; since *S*s working under DP had longer rests, they required more time, as measured from the beginning of the experiment, to get in the same amount of practice as *S*s working under MP. Most *E*s have apparently operated under the assumption that the advantage DP has over MP is legitimately demonstrated only when the actual amount of practice is equal, and have therefore permitted the total time (practice time plus resting time) to vary. We may question this assumption on two grounds. First, in two articles Kimble (**7, 8**) attempted to answer the question whether work or rest was the more important variable. On the basis of his first analysis Kimble concluded that the amount of work was more important, but in the second paper he reversed his position and concluded that the question could not be answered at present. We should also mention here the striking results recently presented by Kimble (**10**). Here it was shown that, with the exception of the first 5 min. of practice, an MP group subsequently made all its performance gains during rest and all its performance losses during practice.

The second reason for questioning the procedure of equating practice in DP and MP groups comes from the studies of Hilgard and his students (**3, 4**) in which the procedure was not used. These investigators held constant the length of the experimental session on the pursuit rotor and therefore permitted MP groups to have considerably more actual practice than DP groups. (This procedure will hereafter be called the Hilgard Technique.) When scores were plotted as a function of the length of session, DP *S*s still showed superior performance. By the end of the session the performance differences between DP and MP groups were statistically significant in favor of the DP *S*s, even though the MP *S*s had had more practice.

The purpose of the present experiment is to make further use of the procedure of equating total practice plus resting time of *S*s working under DP with that of *S*s working under MP in an attempt to answer a somewhat different question. This question may be stated as follows: does the *performance* superiority of DP *S*s obtained by the Hilgard Technique also represent a *learning* difference? The distinction between learning and per-

[1] This research was supported by a grant from the Graduate School, Northwestern University. The author wishes to thank Mr. R. H. Hughes, Mrs. Betty P. Miller, and Mr. Robert Goldbeck for their assistance in the study.

formance in motor skills has become important as a result of recent theoretical developments. Borrowing the concepts of conditioned inhibition ($_sI_R$) and reactive inhibition (I_R) from Hull's (**5**) conditioning theory, Ammons (**1, 2**), Kimble (**6, 7, 8, 9, 10**), and others have shown that because of the development of these inhibitory components in motor learning, plotted performance curves for DP and MP represent only varying degrees of approximation to "true" acquisition curves. The rationale of the present experiment may then be stated more completely: since in experiments using the Hilgard Technique MP involves more practice (work) in the same length of time, more I_R should develop and it follows that the MP performance curves will be depressed below those for DP where less I_R should have developed. Therefore, it appears reasonable to assume that MP groups have *learned* as much, or perhaps even more, than DP groups by the ends of the experimental session, although their performance curves are temporarily depressed. It follows that in order to test whether *S*s have learned as much under MP we must first allow a relatively long rest for I_R to dissipate and then compare performance of groups who worked under different degrees of spacing of practice before rest, but who, after the rest, now work under the same degree of spacing of practice. In short, can intervals of rest be directly substituted for intervals of practice in some cases, with no reduction in final level of learning attained? This is the experimental design of the present study.

Because of the lack of agreement on the defining operations for $_sI_R$, what role it may play in such a design cannot be predicted. However, an attempt will be made later to show whether $_sI_R$ could have occurred.

Procedure

Four groups of undergraduate women, totaling 157, served as *S*s and learned the rotary pursuit task. They were assigned to the groups at random. For all *S*s the length of the experimental session was 20 min. This was divided as follows: 5 min. pre-rest practice, 10 min. rest, and 5 min. post-rest practice. Thus, with the pre-rest session the same length for all *S*s, the actual amount of practice is not equal for groups using different degrees of spacing of practice.

During the 5-min. pre-rest period, two of the groups worked under DP (10 sec. practice, 20 sec. rest). The other two groups worked under MP (continuous practice for 5 min.). A trial was arbitrarily defined as 30 sec. of time, thereby dividing the 5 min. period into ten trials. Since DP *S*s actually practiced only one-third as much as MP *S*s, to permit comparison scores in all cases were converted to percentages of time on target, i.e., per cent time on target during 10 sec. for DP groups and 30 sec. for MP groups.

Following the pre-rest session, all groups were given a 10 min. rest. The length of the rest was determined on the basis of Ammons' results (**2**) where it was shown that all or nearly all I_R has dissipated after 10 min. During the rest *S*s faced away from the apparatus and read magazines or were engaged in conversation by *E*, to minimize symbolic practice. Near the end of the rest *S*s were told what degree of massing or distribution they would use during post-rest practice. The possible effect of this knowledge will be discussed later.

During the 5-min. post-rest session, one of the groups that had worked under DP before rest now worked under MP, and similarly, one of the pre-rest MP groups switched to DP after the rest. The other two groups practiced after rest in the same way as before.

The records of a few *S*s were discarded because at some time during practice the stylus slipped off the turntable, resulting in a very poor score for that trial. The remaining 157 *S*s were divided as follows: group MP-R-MP, 39 *S*s; group MP-R-DP, 40 *S*s; group DP-R-MP, 37 *S*s; group DP-R-DP, 41 *S*s. The abbreviation for each group indicates the chronological order of conditions for that group; i.e., type of practice before the rest-rest (R)-type of practice after the rest.

The rotary pursuit apparatus consisted of a turntable, radius 14.3 cm., driven by a 60 rpm motor. A brass disc .87 cm. in radius was set into the surface of the turntable. The center of the disc was 7.8 cm. from the center of the turn-

table. The *S* held a hinged brass stylus which, when in contact with the disc, completed the electrical circuit to the clocks. Time on target was recorded by two .01-sec. clocks which alternated in recording every 15 sec. of rotor time for groups using MP, thus 20 scores were obtained during 5 min. of practice in such groups. These were then combined to give ten scores, as indicated above.

Results

The performance curves are shown in Fig. 1. In the figure the per cent time on target is shown for all groups for both pre-rest and post-rest practice.

Pre-rest performance.—The DP groups show superior performance without reversal for the last six pre-rest trials even though the MP groups have had three times as much actual practice. This confirms the findings of Hilgard and his associates (**3, 4**). However, the difference between the DP and MP curves is small, and is less than is usually found in experiments where the amount of practice was equal, as might be expected.

The difference between the pre-rest curves was tested for significance by the following method. The time on target in seconds was summed for Trials 9 and 10 for every *S*. This sum was then converted to a percentage. Since many of these percentages were small, the percentages were then converted to angles, as recommended by Snedecor (**11**). The mean angles and the standard errors are shown in Table I.

The difference between the means of the two pre-rest DP groups was not significant ($t = .01$), and neither was the difference between the two pre-rest MP groups ($t = .32$). Therefore, the two pre-rest MP groups and the two pre-rest DP groups were combined to test the pre-rest performance difference resulting from DP. The resulting t was 2.04 ($p < .05$). We may conclude that *S*s working under DP showed superiority in performance over *S*s working under MP at the end of the pre-rest session.

First-trial post-rest performance.—All groups showed a gain (reminiscence) on the first trial after rest. The DP groups appear to show as much reminiscence as the MP groups. Since there was no control group in which no rest was given, the absolute amount of reminiscence cannot be measured. However, the relative reminiscence resulting from the pre-

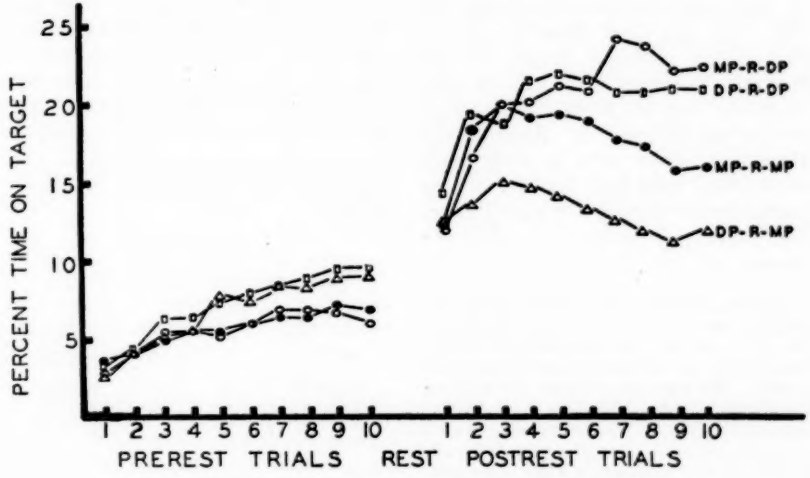

Fig. 1. Performance curves for various combinations of massed (MP) and distributed practice (DP) before and after a 10-min. rest period

TABLE I

MEAN ANGLES OF THE PER CENT TIME ON TARGET DURING TRIALS 9 AND 10 OF PRE-REST PRACTICE

Group	*N*	Mean	σ_M
MP-R-MP	39	14.34	1.07
MP-R-DP	40	13.87	1.01
DP-R-MP	37	16.29	0.99
DP-R-DP	41	16.28	1.09

rest distribution of practice can be determined. The method employed was to obtain the mean per cent of time on target for Trials 9 and 10 of pre-rest practice for each *S*. Next, the per cent of time on target was determined for each *S* on the first post-rest trial. For the two groups given DP after rest, this was simply the percentage of 10 sec., the means of which are shown as the first post-rest trial in Fig. 1. For the groups given MP after rest, the percentages were based on only the first 15 sec. of the 30-sec. trial. These points are not shown in Fig. 1. Although reminiscence is sometimes measured from the high point of post-rest curves, the first trial was used here because of the widely differing shapes of the curves. The next step was to subtract the pre-rest from the post-rest percentage for each *S*. Again, since these gain scores were in most cases small, they were first transformed to angles before testing for significance. The mean gain scores, in angles, are shown in Table II.

Analysis of variance could not be used to test whether there was any overall significance among the reminiscence gains, because the variances of the gain distributions were not homogeneous. We may, however, use *t* to evaluate the differences among the means of Table II as long as we are conservative in our interpretation of the *t* values (11). Actually, none of the differences between the means in Table II is significant. The largest *t*, between the means of Groups MP-R-MP and DP-R-DP is 1.69. When the two pre-rest MP groups were combined in order to make a single test against the two pre-rest DP groups combined, again the difference was not significant ($t = .59$).

We are forced to conclude that although all groups apparently showed a reminiscence gain, there were no reliable differences among the groups in the amount of gain obtained, probably largely due to the great variability in the gain distributions. Nevertheless, it should be pointed out that the two largest gains in Table II result from the two groups who worked under DP after rest, and the two smallest gains come from the two post-rest MP groups. Since the advantage of post-rest DP over post-rest MP could have no direct influence on the first post-rest trial, the non-significant tendency toward superiority of the post-rest MP groups may have resulted from the *Ss*' knowledge of the degree of spacing of practice that was to be used after the rest.

Final post-rest performance.—Although there are obvious differences in trend among the curves, we shall deal only with the final positions of the curves. It may be noted by inspection that groups given DP after rest are superior to groups given MP. Also, pre-rest MP groups are superior to groups given pre-rest DP after rest, regardless of the practice condition used.

TABLE II

MEAN REMINISCENCE GAIN SCORES IN ANGLES *

Group	*N*	Mean	σ_M
MP-R-MP	39	7.55	2.21
MP-R-DP	40	10.94	1.91
DP-R-MP	37	8.55	1.93
DP-R-DP	41	12.04	1.48

* Reminiscence gain = difference between mean per cent time on target during the last two pre-rest trials and the first post-rest trial.

TABLE III

MEAN ANGLES OF THE PER CENT TIME ON TARGET DURING TRIALS 9 AND 10 OF POST-REST PRACTICE

Group	Mean	σ_M
MP-R-MP	22.35	1.22
MP-R-DP	27.22	1.47
DP-R-MP	19.25	1.06
DP-R-DP	26.25	1.25

The mean per cent time on target during the last two post-rest trials for each of the four conditions is shown in Table III after conversion to angles (for each *S*).

Again, heterogeneity of variance precludes the use of the *F*-test to evaluate the data of Table III.

The *t* between the two post-rest MP groups was 1.91, and between the two post-rest DP groups was .50. If we accept the null hypothesis in these cases, it can be concluded that at the end of post-rest practice, groups working under similar conditions have reached similar levels of performance, regardless of differing pre-rest histories. However, the two post-rest MP groups are widely separated after the *first* post-rest trial, and it seems proper to entertain the hypothesis that post-rest performance under MP is superior when pre-rest training is under MP rather than DP.

In Table III the difference between MP-R-MP and MP-R-DP is significant at the .02 level ($t = 2.55$); between MP-R-MP and DP-R-DP at the .05 level ($t = 2.23$); between MP-R-DP and DP-R-MP at the .001 level; and between DP-R-MP and DP-R-DP at the .001 level. Thus, any post-rest DP group is superior to any post-rest MP group, regardless of its pre-rest history. This conclusion is probably true only for the levels of practice achieved in this experiment; if more than ten trials had been given after the rest, we might expect the differences between post-rest MP and DP groups to lessen as the groups now using MP cease showing losses in performance and begin to improve. There is a suggestion in Fig. 1 that this inflection in the curves of the post-rest MP groups occurs between Trials 9 and 10.

DISCUSSION

During the 10-min. rest the *S*s were told by *E* what degree of spacing of practice they were to use after the rest. This was done to eliminate any effect of surprise which might have occurred in the two groups that were to change to a different degree of spacing during post-rest practice. Perhaps it would have been better to have left this variable uncontrolled since we have no way of knowing how post-rest scores were affected by *S*'s anticipation of what the new practice condition would be like. It is even difficult to evaluate the *S*s' anticipations since they had no knowledge of any practice condition except the one they had already used. As a consequence, part of the severe depression in the post-rest curve of group DP-R-MP may be due in part to this factor. It is not likely to be the entire explanation, however, since in other studies losses have occurred when *S*s working under relatively distributed conditions were changed to relatively massed conditions (**3, 4**).

The reminiscence gains obtained were unusual. Groups using DP before rest showed as much gain as groups using MP. One suggestion can be made concerning this finding. Female *S*s do not do as well as males on the pursuit rotor. If women find the task more difficult, then perhaps they find it more effortful. Effort is one of the defining operations for the

development of I_R. Thus it is possible that even *S*s working under DP exerted enough effort so that relatively large amounts of I_R developed, more than could be dissipated in the 20-sec. rests. This could explain why DP *S*s showed *some* reminiscence, but not why they showed *as much* reminiscence as MP *S*s. In this connection it may be noted that one of the assumptions concerning I_R is that it develops rather quickly to a critical or threshold level, and with additional practice no more is developed, or more precisely, the rate of development and dissipation become equal (**9**). This assumption is based on the observation that reminiscence gains rise rather quickly to a maximum relatively early in practice and that with additional practice there are no further increases in reminiscence. If we accept these assumptions it would be necessary to say that in the present experiment the threshold of I_R was reached in both DP and MP *S*s before rest.

Although there were no significant differences among the reminiscence gains of the various groups, somewhat better matching of the mean gains shown in Table II is obtained if we pair groups working under the same degree of spacing after rest instead of *pre-rest* MP and DP groups. Again, whether this is due to the *S*s' anticipations of the post-rest session can only be left to speculation, but may be pertinent to attempts to relate reminiscence to motivational changes (**10**).

The main purpose of the experiment was to determine whether the performance superiority of DP groups over MP groups, which occurs even when the DP *S*s have had less practice, also represents a learning difference. If it does, then there should be a difference between the groups after they have been allowed to work for a time under comparable conditions of spacing of practice. The direction of the final difference would, of course, depend on whether the DP *S*s had learned more or less than MP *S*s before the rest. Actually, no significant difference between pre-rest MP and DP groups could be shown at the end of the post-rest session. This was true both for massed and distributed post-rest practice. Thus, although at the end of the pre-rest session *S*s working under DP were significantly superior in performance, they had not learned any more. Another way of putting it is to say that pre-rest DP *S*s showed equal learning and superior performance when compared to pre-rest MP *S*s, although they had practiced only one-third as much. It seems that in a motor task in which resting time is so important, as in the case of the pursuit rotor, equally good results can be obtained by measuring learning as a function of total practice plus resting time; i.e., rest intervals can be directly substituted for practice periods in some cases, a time-saving procedure in studies in which it is necessary to run *S*s under different degrees of spacing of practice.

The difficulty of attempting to relate performance levels on the rotor to actual practice time is further emphasized by the differences among the four groups at the end of the experiment. At the conclusion of the experiment one group, MP-R-MP, had had 600 sec. of practice, two groups, MP-R-DP and DP-R-MP, had had 400 sec., and group DP-R-DP had had 200 sec. These different amounts of practice do not seem in any way related to the rank order of the groups in the final performance level attained.

Finally, is there any evidence for conditioned inhibition ($_sI_R$) in the data? We have previously mentioned

that there is disagreement as to just what conditions are necessary for ${}_sI_R$ to develop. Hull (5) seems to think that when I_R is present at the time a rest occurs, an increment to ${}_sI_R$ will develop. Since Kimble (10) holds that it is necessary to have relatively long periods of practice (longer than the 5 min. used in this study) under conditions of extreme massing to produce ${}_sI_R$, the data are not pertinent to his view.

If Hull's theory of the development of ${}_sI_R$ is correct, then it should have developed in the DP *Ss* before rest. Both defining conditions were present: (a) a certain amount of I_R, inferred from the reminiscence gain, and (b) rests. Since it has commonly been assumed that ${}_sI_R$ does not dissipate over relatively short rests, such as the 10 min. used here, it would follow that when post-rest practice begins, groups which had used DP before the rest would start practicing with a disadvantage as compared to pre-rest MP groups, the disadvantage of ${}_sI_R$. Beyond the speculation that the ${}_sI_R$ might have contributed to the slight but not significant superiority of pre-rest MP *Ss* over pre-rest DP *Ss* under both conditions of post-rest practice, the effect of this variable cannot be evaluated.

Summary

An attempt was made to determine if the performance superiority of *Ss* working under distributed practice over *Ss* working under massed practice also represents a learning difference in the case where the length of the experimental session (total practice plus resting time) is the same for all *Ss*. This means that the amount of practice is not equal for *Ss* working under different degrees of spacing of practice.

A total of 157 female *Ss*, in four groups, were run on the pursuit rotor through a 5-min. pre-rest session, a 10-min. rest, and a 5-min. post-rest session. During the pre-rest session, two groups worked under massed practice and two under distributed practice. During the post-rest session, one of the pre-rest massed practice groups was given distributed practice, and one of the pre-rest distributed practice groups was given massed practice. The other two groups practiced under the same condition as they had used before the rest.

The results and conclusions were as follows:

1. At the end of the pre-rest session, the distributed practice *Ss* were performing significantly better than massed practice *Ss* even though the former had had only one-third as much actual practice as the latter.

2. All groups showed a relative reminiscence gain, measured as the difference between scores at the end of the pre-rest session and the score on the first post-rest trial. There were no significant differences among the groups in the amount of reminiscence shown.

3. At the end of the post-rest session there was no significant difference between the two groups that were given distributed practice after the rest, nor between the groups that had worked under massed practice after the rest. Post-rest distributed groups were significantly superior to post-rest massed groups.

4. It was concluded that *Ss* who had used distributed practice before rest had not only shown superior performance, but had learned as much as massed practice *Ss*, even though they had had considerably less practice.

(Manuscript received
November 27, 1950)

References

1. Ammons, R. B. Acquisition of motor skill: I. Quantitative analysis and theoretical formulation. *Psychol. Rev.*, 1947, **54**, 263–281.
2. Ammons, R. B. Acquisition of motor skill: II. Rotary pursuit performance with continuous practice before and after a single rest. *J. exp. Psychol.*, 1947, **37**, 393–411.
3. Cook, B. S., and Hilgard, E. R. Distributed practice in motor learning: Progressively increasing and decreasing rests. *J. exp. Psychol.*, 1949, **39**, 169–172.
4. Hilgard, E. R., and Smith, M. B. Distributed practice in motor learning: Score changes within and between daily sessions. *J. exp. Psychol.*, 1942, **30**, 136–146.
5. Hull, C. L. Behavior postulates and corollaries—1949. *Psychol. Rev.*, 1950, **57**, 173–180.
6. Kimble, G. A. An experimental test of a two-factor theory of inhibition. *J. exp. Psychol.*, 1949, **39**, 15–23.
7. Kimble, G. A., and Bilodeau, E. A. Work and rest as variables in cyclical motor learning. *J. exp. Psychol.*, 1949, **39**, 150–157.
8. Kimble, G. A. A further analysis of the variables in cyclical motor learning. *J. exp. Psychol.*, 1949, **39**, 332–337.
9. Kimble, G. A. Performance and reminiscence in motor learning as a function of the degree of distribution of practice. *J. exp. Psychol.*, 1949, **39**, 500–510.
10. Kimble, G. A. Evidence for the role of motivation in determining the amount of reminiscence in pursuit rotor learning. *J. exp. Psychol.*, 1950, **40**, 248–253.
11. Snedecor, G. W. *Statistical methods*. Ames: Iowa State College Press, 1946.

EXPERIMENTAL STUDIES IN ROTE-LEARNING THEORY: IX. INFLUENCE OF WORK-DECREMENT FACTORS ON VERBAL LEARNING

BY CARL I. HOVLAND AND KENNETH H. KURTZ

Yale University[1]

Two major types of explanation for reminiscence (and the advantage of distributed practice) have been advanced. The first type is in terms of *learning* factors, e.g., the dissipation during a rest interval of associative interferences built up during learning. In the second category are explanations in terms of work-decrement and motivational factors. Here are stressed loss of interest ("boredom") and even physical fatigue which develop during learning and then are overcome during the period of rest, resulting in better subsequent *performance*. In explanations of reminiscence in motor learning, work-decrement factors tend to be stressed, sometimes through the employment of the "reactive inhibition" concept (1, 7). In the field of verbal learning, explanations tend to be almost exclusively of the associative interference variety (6).

In the typical reminiscence experiment it is extremely difficult to separate the learning and performance factors since both proceed concurrently. In the present study an attempt was made to assess separately the effects of work-decrement factors by introducing varying amounts of mental work prior to learning in a typical reminiscence type experiment. Whatever interference effects are produced by learning would thus be common to the various conditions, and differences in rate of recovery during rest can be attributed to prior mental work. The type of mental work (difficult addition problems) was selected to be as unrelated as possible to the type of learning studied, so as to minimize transfer of training effects.

Crucial to the logic of the experiment are the hypotheses that the effects of work will be dissipated with the passage of time and that the greater the accumulation of the effects of work-decrement the greater will be the recovery with the passage of time. As in the typical reminiscence experiment, a rest pause was introduced after the attainment of a fixed criterion of partial learning. This pause should permit the dissipation of accumulated work decrement effects. Comparable data were secured when the rest pause was omitted and learning continued to mastery without interruption.

Experimental Procedure

Three conditions of prior mental work were employed: (a) continuous mental work followed immediately by learning, (b) mental work but with a 2-min. rest pause, filled with color naming, between the end of work and the beginning of learning, and (c) a control condition involving no prior mental work. Within each work condition the conventional pair of reminiscence treatments was employed: one in which a 2-min. rest period was introduced after attainment of a criterion of 7/12 syllables correct; the other in which learning continued without interruption to mastery. Thus, the design involved six conditions representing the two reminiscence treatments for each of the three work conditions. Each *S* learned a total of 12 lists, two under each

[1] The writers wish to express their appreciation to Fred D. Sheffield, Claude E. Buxton, Gregory A. Kimble, and Richard P. Runyon for reading the manuscript and making helpful criticisms and suggestions.

of the six major conditions, after completing four preliminary practice sessions.

To test a suggestion of Irion (8) that color naming at the same speed as syllable presentation may produce a rhythmic set favorable to learning, a minor variation was introduced in the two control conditions involving no prior mental work. One of the two lists learned to 7/12 mastery before rest and one learned to complete mastery without rest were preceded by a 2-min. period of color naming; the other list under each condition was learned without prior color naming.

Order of presentation.—To balance out practice effects the sequence of conditions was systematically varied between *Ss* so that each of the conditions appeared in each position, and each condition followed and preceded every other condition in counterbalanced order. As far as could be arranged, the 12 sessions were held one a day for six days a week, no sessions being held on Sunday. In a few unavoidable instances the *Ss* served on fewer than six days a week, prolonging the total period. Assignment of the 12 lists to the 12 sessions was randomly determined for each *S* with the single restriction that each *S* should use each list only once.

Results from ten of the 144 experimental sessions were rejected on the grounds of inaccurate scoring or of deviations from standard procedure caused by *E*'s error or by mechanical failures of apparatus. The conditions for which the data were rejected were repeated in five instances on the day immediately following, postponing all the remaining sessions one day, and in five instances at an additional session after the completion of the remaining scheduled sessions. Auxiliary lists prepared in the same manner as the regular lists were used in these repeat sessions.

Preliminary practice.—To reduce practice variance and insure that *Ss* were familiar with the various instructions and tasks involved, each *S* learned four preliminary lists under four conditions. The conditions were chosen to include all the types of transition from one activity to another involved: (a) Learning to mastery without rest immediately after continuous mental work; (b) learning to mastery without rest following continuous mental work and an intervening rest period; (c) learning to 7/12 mastery, rest, and then complete mastery following continuous mental work and an intervening rest; and (d) learning to 7/12 mastery, rest, and then complete mastery without prior mental work. The sequence in which these were given was systematically varied between *Ss* so as to avoid emphasizing any of the conditions by primacy and forming any systematic set regarding the sequence of conditions. Three days were spent in practice learning, two lists being learned on one of the last two days.

Apparatus.—The Hull memory drum was used for the presentation of the syllables and for the exposure of the colors named during rest periods. The apparatus and *E* were situated behind a black screen 6 ft. high by 4 ft. wide, with a 5 in. by 4 in. opening for displaying the syllables. Signal lights were placed to the right and left of the aperture and were used together with a buzzer as signals for transitions between activities in the manner described below.

Nonsense-syllable lists.—The learning materials consisted of 12 nonsense syllables composed of two consonants separated by a vowel. The syllables were typewritten on bands of semi-glazed white paper in ¼ in. upper case black letters and presented one at a time in a fixed serial order at a 2.2-sec. rate. The first syllable was preceded by an asterisk presented for the same interval. Except for the 2-min. rest pause introduced after 7/12 mastery under certain conditions, the trials were massed, with the initial asterisk following immediately after the twelfth syllable. The syllables were learned serially by the anticipation method, and were pronounced as a single unit. The lists were derived from Melton's (10) lists of 12 nonsense syllables. They were made to conform (with the two exceptions noted below) not only to the intra-list rules specified by Melton but also to three further rules added by the present authors: (a) syllables ending in *IW*, *UW*, *UY*, and *IY* were rejected because of difficulty of pronunciation; (b) the mean Glaze association value (4) of the syllables in each of the lists used in the main experiment fell within the range 28.9 ± 3.0; and (c) no three consecutive syllables had an initial *X* and either an initial or final *Z* in common. The additional restraints introduced by these three rules made it necessary in three of the lists to have two syllables with the same final consonant. In one list the same consonant appeared as the first letter of the twelfth syllable and the third letter of the first syllable.

Color-naming.—A row of 1-in. vari-colored squares of paper was pasted on each of the bands of syllables so that they could be presented in the left-hand window in the same manner as the syllables, which were presented in one of the three remaining windows. The *Ss* were instructed simply to name the colors whenever they appeared. Color naming was always introduced in the following manner: the ongoing activity of adding, learning, or resting was ended by sounding the buzzer for a 5-sec. period and simultaneously presenting the left-hand panel light. At the end of this signal the colors were presented for 115 sec. by opening the appropriate shutter. Simultaneously with the

closing of the shutter the buzzer was sounded and the right-hand light presented for a 5-sec. interval, at the end of which the syllable-window shutter was opened, exposing the initial asterisk, and learning was begun. Under the conditions where work or rest was followed immediately by learning, the first signal and the color naming in the above sequence were omitted.

Mental work.—Mental work consisted of 10 min. of difficult problems in addition. Each problem consisted of adding fifteen 8-digit numbers. These were reproductions of sections of Tippett's tables of random numbers with the zeros in the left-hand column changed to nines. Six different sets of eight problems each were mimeographed in standard typewriter numerals. A different set was given at each session for which addition was scheduled. When *Ss* had used all six sets the cycle was repeated.

Subjects.—Twelve Yale College students served as paid *Ss*. Eleven were undergraduates and one was a graduate student. The median age was 21.5 years with a range of 19–28 years.

Instructions.—Oral instructions similar to those used previously in these laboratories were given to *Ss* in a uniform way at the first practice session, with the modifications necessary for the particular character of the present study. Details concerning the procedures for learning, computation, and color naming and the transition between these activities were covered. The rationale of the experiment was given as a study of the correlation between rote-memorization and arithmetical abilities and of the change of these abilities with practice. An attempt was made to have the adding appear as important as the learning, and *Ss* were encouraged to do the computations at top speed. Following the first learning session the importance of trying to anticipate the syllables, even in the face of discouragement, was emphasized. During the practice sessions standard pronunciations were suggested for letters or combinations with which *Ss* had difficulty.

Results

In Table I results are presented for recall following attainment of the 7/12 syllable criterion with and without a rest pause for the three conditions of prior work, and the number of trials required to reach the 7/12-syllable criterion. Within each condition the pairs given "rest" and "no rest" treatments did not differ significantly in number of trials to reach the criterion. The results of most direct interest are those presented in the last column of Table I, which represent the differences in recall under interrupted and continuous learning. It will be observed that absolute reminiscence is obtained only following the continuous work condition, but the relative effects are in line with the prediction from the operation of work-decrement

TABLE I

Trials Required to Reach the 7/12-Syllable Criterion and Differences between the Number of Syllables Recalled on the Criterion and the First Post-Criterion Trials *

Condition	Trials to 7/12 Criterion			Post-criterion—Criterion Recall Difference						
	No Rest	Rest	Diff.	No Rest		Rest		Difference		
	Mean	Mean	t	Mean	σ_M	Mean	σ_M	Mean	σ_M	t
I. Continuous mental work	6.17	6.63	1.06	−0.96	.42	−0.79	.28	0.17	.39	0.44
II. Cont. mental work and pre-learning rest	6.67	6.71	0.07	−0.38	.38	−1.17	.27	−0.79	.48	1.65
III. No mental work	6.63	6.92	0.51	0.17	.30	−1.29	.38	−1.46	.42	3.48
Difference between I and III				−1.13	.50	0.50	.41	1.63	.63	2.59

* Each mean is based on two replications for each of 12 *Ss*.

factors, i.e., the beneficial effect of rest is greatest with continuous work and least when no prior mental work is involved.

The group which had prior mental work but also had a rest pause to permit the reduction of accumulated decremental effects before beginning learning showed an effect intermediate between the two other groups but did not differ significantly from either. The difference in amount of "reminiscence" for the two extreme groups is significant at the .01 level, using the single tail test. The relative improvement resulting from rest for the two work conditions is brought out in Fig. 1. Here the results for the control condition are taken as a base line and the shaded portions indicate the greater gain during rest for the two work conditions.

Effect of color-naming.—As mentioned earlier, it has been suggested by Irion (**8**, p. 340) that the effect of naming colors presented at the same rate as that used for syllable presentation will be to increase the rate of learning. In the present experiment, data bearing on his prediction were obtained through the comparison of the subgroup of the control conditions in which color naming preceded learning with the subgroup in which there was no prior color naming. Contrary to Irion's expectation, no facilitation of recall following color naming was obtained. The slight difference obtained is in a direction opposite to his prediction. The mean number of syllables recalled on the second learning trial was .50 with prior color naming and .79 without; $p = .15$ (both tails). The mean number of trials to achieve 7 out of 12 syllables correct was 6.83 with prior color naming and 6.71 without. It appears that under our conditions an interference is produced by color naming which is a more potent influence than the "set-invoking" facilitating effect postulated by Irion.

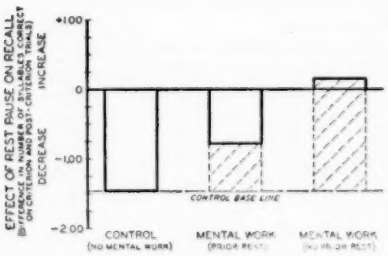

FIG. 1. Increments or decrements in recall attributable to 2-min. rest pause introduced following attainment of criterion of 7 out of 12 syllables correct under three sets of experimental conditions. Shaded portions represent differences in effect for the two work conditions using results from the control conditions as a base line.

DISCUSSION

When the study was designed it was anticipated that a small but possibly significant amount of reminiscence following partial learning would be obtained under the conditions which involved no mental work (control) and that the extent of reminiscence would either be augmented or remain constant following the conditions involving prior mental work, depending on the significance of work-decrement factors. The results actually indicate that forgetting rather than reminiscence is obtained during the rest pause under control conditions, and that absolute reminiscence occurs only when continuous work without a rest pause has preceded the learning. This loss under control conditions is not consistent with previous experiments by Ward (**14**), Hovland (**5**), and Buxton (**3**) for nonsense syllable learning, but is in line with experiments by Melton and Stone (**11**) and Noble (**12**) for meaningful adjectives. The pronounced effect of prior work on recall after partial learning shown in the

present study suggests the hypothesis that part of the variation in results of experiments may be attributable to differences in the prior activity of *Ss* before beginning the learning series. It is possible that in some experiments the conditions are set up in such a way that *Ss* start learning directly after prior work while in others initial relaxation is induced. At least this lead may be worth exploring in view of what Buxton has called the "now-you-see-it-now-you-don't" character of reminiscence (**2**).

The reduced level of nonsense syllable performance following rest(which was filled with color-naming) appears to be primarily restricted to the immediate post-rest recall. When relearning rather than immediate recall is used for measuring the effects, reminiscence is obtained. Under all three sets of conditions there is a decrease in the number of trials to reach the criterion of 12/12 syllables correct following a rest pause, as compared with the number under the uninterrupted condition. In this respect, the present results are consonant with those of Noble (**12**), who found no reminiscence on the first post-rest trial but did find a beneficial effect on learning to the criterion following the rest pause. The experiments of Ward (**14**), Hovland (**5**), Melton and Stone (**11**) and Noble (**12**) agree closely in showing this improvement during the continuation of learning following the rest pause. No clue is provided by the present study as to why improvement on the first post-rest trial was found in previous experiments in these laboratories by Ward (**14**) and Hovland (**5**) but not under the control conditions in the present study. About the only known difference in procedure was the elaborate system used in the present study for signalling the change from learning to rest conditions and back again to learning conditions. It seems rather unlikely that the buzzer-light signal system could alone be responsible for producing disruptive effects. If that were the main cause it might be thought that practice in making the shift from learning to color naming (and the reverse) would overcome the effect, but investigation of our data showed no sizeable differences between the first and second cycle of trials.

The foregoing considerations suggest the possibility that under the present conditions the effect of the "rest" in the "rest pause" may be counteracted by some disruptive effect associated with color naming and/or the interruption of learning. To test the initial expectations of the experiment this disruptive effect would have to be subtracted. How the various factors involved would operate could perhaps be clarified by an attempt to partial out the various components that enter into the results of Table I. We take up first the results concerning the difference between recall on the criterion trial and on the first post-criterion trial under the three "no rest" conditions, presented in the first column. Here we should expect that some learning would take place between the criterion trial and the following trial, and the rate of such learning should be less following work if work-decrement factors operate. Opposed to this learning gain would be the *selection effect* produced by interrupting learning when a fixed criterion is reached, which tends to make performance on the criterion trial artificially high. That is, when we select the first trial on which a given number of syllables are recalled, we are taking the peak of a fluctuating series, and the next trial will therefore tend to show a loss, particularly if one

is on a relatively flat portion of the acquisition curve (9). Thus, the differences between recall on the criterion and post-criterion trial presented in the "no rest" column may be viewed as a joint effect of a loss resulting from artificial selection on the criterion trial and a gain attributable to improvement from trial to trial during learning. Since the selective effect may be regarded as relatively constant, variations between different conditions primarily reflect differences in acquisition rate. This may be made clearer by using hypothetical numerical values. Let us assume that if there were no learning taking place from trial to trial the selective effect would result in a loss of, say, a syllable and a half. This would be expected to exert about the same effect under the three conditions. The difference in net change between the three conditions would then be due to differential rates of learning. In the hypothetical example these values are obtained by subtraction of the constant loss from the "net effect" in Table I. The two factors contributing to the net effect would then be partialled out as indicated in Table II.

In the case of the "rest" conditions we should have operative the same factors as under the "no rest" conditions, plus two additional factors: a disruptive effect associated with color naming (as suggested above) and recovery during the rest pause from decremental effects of prior work. A similar subdivision of the "net effect" under these conditions in Table I can be made into the four suggested factors. Again employing the hypothetical loss of 1.50 syllables because of the selective effect of the criterion, and assuming a constant loss of two syllables attributable to the disruptive effect of color-naming, the resulting analysis is shown in the lower part of Table II.

TABLE II

HYPOTHETICAL ANALYSIS OF "REST" AND "NO REST" RESULTS

Analysis	Mental Work	Mental Work + Rest	No Mental Work
	Rest during Learning		
1. Loss due to selective effect	−1.50	−1.50	−1.50
2. Net effect (from Table I)	−0.96	−0.38	+0.17
3. Gain due to learning (*2−1*)	+0.54	+1.12	+1.67
	No Rest during Learning		
4. Loss due to selective effect	−1.50	−1.50	−1.50
5. Gain due to learning (from *3*)	+0.54	+1.12	+1.67
6. Loss due to disruptive effect	−2.00	−2.00	−2.00
7. Net effect (from Table I)	−0.79	−1.17	−1.29
8. Gain due to recovery from work (*7−(4+5+6)*)	+2.17	+1.21	+0.54

Thus, it would be possible for the "no rest" conditions to reflect a differential acquisition rate associated with amount of prior work and fatigue, and for the "rest" conditions to reflect the same effects plus a gain from rest increasing with amount of prior work. The difference shown in the third from last column of Table I would thus be the resultant of a number of factors, some operating to increase and some to decrease amount recalled. If the assumed constant effect attributed to disruption associated with color naming is thus subtracted from the obtained changes, the results fall in line with those anticipated when the experiment was begun. Then the difference between "rest" and "no rest" conditions brings out the improvement attributable to rest shown in the last row of Table II. This *gain* due to recovery from decremental effects is greatest under the conditions where maximum work-decrement factors would be expected to operate.

While the present study thus suggests that work-decrement factors may play a significant role in verbal learning, the data shed little light on the nature of the underlying causal factors. The term "work-decrement" has been loosely used in the literature (cf. **13**) to cover a wide range of phenomena ranging all the way from muscular fatigue to subtle motivational changes ("loss of interest," etc.). In some studies the effects are derived primarily through involvement of the same responses (as in reactive inhibition studies) and in others through transfer effects involving different responses (as in the present experiment). Further research is greatly needed to differentiate analytically the various component factors involved in work-decrement phenomena.

Summary

1. The present experiment was designed to determine the role in rote-learning of work-decrement factors independently of associative interference factors by studying the differential effects of rest pauses during learning following work and no-work conditions. Each of 12 *S*s learned lists of nonsense syllables by the serial anticipation method under the two treatments (with and without interpolated rest) of a reminiscence paradigm following three conditions of prior work. The three conditions were: (a) 10 min. of addition followed immediately by learning; (b) 10 min. of addition with 2 min. of rest (color naming) between work and learning; and (c) control, without prior work.

2. The effect of the rest interpolated after partial learning upon subsequent recall was significantly more beneficial following conditions of work immediately preceding learning as compared with control conditions. In the former condition the effect was a net gain; in the latter, a loss. Results for the remaining work condition were intermediate between the extreme groups and showed a net loss.

3. Results of two subgroups (with and without 2 min. of color naming preceding learning) under control conditions do not support Irion's (**8**) suggestion that color naming should establish a set to facilitate learning. Instead, color naming tended to interfere with recall on the second learning trial, although not to a statistically significant degree. The same was true of the trials to the criterion of 7/12 mastery of the list.

4. An analysis of immediate and delayed recall following the criterion of partial learning was made in terms of the joint effects of four factors: (a) trial-to-trial fluctuations in performance; (b) learning increments; (c) a disruptive effect of color naming; and (d) recovery from work decrement.

5. The absence of reminiscence in recall under control conditions is discussed, with an analysis of differences between the present results and those of other experiments following substantially the same procedure.

(Manuscript received
November 30, 1950)

References

1. Ammons, R. B. Acquisition of motor skill: I. Quantitative analysis and theoretical formulation. *Psychol. Rev.*, 1947, **54**, 263–281.
2. Buxton, C. E. The status of research in reminiscence. *Psychol. Bull.*, 1943, **40**, 313–340.
3. Buxton, C. E. Repetition of two basic experiments on reminiscence in serial verbal learning. *J. exp. Psychol.*, 1949, **39**, 676–682.
4. Glaze, J. A. The association value of nonsense syllables. *J. genet. Psychol.*, 1928, **35**, 255–267.

5. HOVLAND, C. I. Experimental studies in rote-learning theory: I. Reminiscence following learning by massed and by distributed practice. *J. exp. Psychol.*, 1938, **22**, 201–224.
6. HOVLAND, C. I. Human learning and retention. In S. S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley, 1951.
7. HULL, C. L. *Principles of behavior*. New York: D. Appleton-Century, 1943.
8. IRION, A. L. The relation of "set" to retention. *Psychol. Rev.*, 1948, **55**, 336–341.
9. MELTON, A. W. The end-spurt in memorization curves as an artifact of the averaging of individual curves. *Psychol. Monogr.*, 1936, **47**, 119–134.
10. MELTON, A. W. Materials for use in experimental studies of learning and retention of verbal habits. Mimeo., Univ. of Missouri, 1941.
11. MELTON, A. W., AND STONE, G. R. The retention of serial lists of adjectives over short time-intervals with varying rates of presentation. *J. exp. Psychol.*, 1942, **30**, 295–310.
12. NOBLE, C. E. Absence of reminiscence in the serial rote learning of adjectives. *J. exp. Psychol.*, 1950, **40**, 622–631.
13. ROBINSON, E. S. Work of the integrated organism. In C. Murchison (Ed.), *Handbook of general experimental psychology*. Worcester, Mass.: Clark Univ. Press, 1934.
14. WARD, L. B. Reminiscence and rote learning. *Psychol. Monogr.*, 1937, **49**, No. 220.

RESPONSE VARIABILITY IN THE WHITE RAT DURING CONDITIONING, EXTINCTION, AND RECONDITIONING [1]

BY JOSEPH J. ANTONITIS [2]

Columbia University

The results of a study by Muenzinger (**8**) and observations by Skinner (**10**) indicate that the ranges of response forms emitted respectively by individual guinea pigs and white rats in instrumental conditioning situations are reduced with continued regular-reinforcement conditioning. Neither of these investigators has, however, clearly defined the relationship which may exist between degree of variability of some measurable aspect of response and number of reinforced training trials. The present study was undertaken principally to obtain further information on this question.

The design adopted for this study yielded additional information concerning response variability (a) during operant level determinations, i.e., a period of unconditioned responding before training, (b) within conditioning and extinction sessions, and (c) during successive extinction and reconditioning sessions following extended regular conditioning. No information is currently available concerning response variability during the first and third of these conditions. With respect to variability within conditioning sessions, Wingfield and Dennis (**12**) found that variability (in terms of frequency of alternation by a rat between two equal paths to food) was higher at the beginning than at the end of series of trials given on the same day. With respect to variability during extinction, studies by Skinner (**10**) of the force and duration of lever-pressing responses emitted by the rat indicate that the ranges of values of these aspects of the response are greater during extinction than during regular-reinforcement conditioning. Other studies of the behavior of animals in a variety of situations indicate that the conditioned form of responding does not persist long in extinction (**4, 5, 6, 9, 11**).

Subjects and Apparatus

Subjects.—The *S*s were 12 male albino rats of Wistar stock, 90–127 days old at the time used in the experiment. The animals were divided at random into two groups of six, and were run in the experiment in the order: three experimental *S*s, three control *S*s, three control *S*s, three experimental *S*s. Photographic records of two *S*s were lost during processing. Two *S*s of the same age and origin were run as replacements after the 12 original *S*s had been run.

Apparatus.—The apparatus was designed to study the variability of horizontal position of occurrence of effective responses made by the nose of the white rat; a floor plan and a separate diagram of the response panel, which was a principal feature of the apparatus, are given in Fig. 1. During a testing session in the apparatus, the sequence of events for the *S* was as follows: (a) *S* was placed in the starting-feeding compartment (*J*) so as to face the open exit door (*H*) and the response panel (*E*, *E'*) after which the door (*L*) to the starting-feeding compartment was closed. (b) *S* could then leave the compartment (*J*) and freely explore the interior of the apparatus. (c) Upon finding the response slot (*M*) in the response panel (*E*, *E'*), *S* could thrust its nose one or more times into the slot; each time an effective nose-thrust occurred, a beam of light from the spotlight (*S*) to the photoelectric cell (*P*) was interrupted and the position of *S*'s nose with respect to the horizontal dimension of the slot was recorded photographically. (d) *S* could then return to the

[1] This article is based on a Ph.D. dissertation presented to the Faculty of Pure Science, Columbia University. The author is greatly indebted to Professor W. N. Schoenfeld under whose guidance this research was performed.

[2] Now at the University of Maine.

starting-feeding compartment (*J*) and, during conditioning sessions, find a food pellet placed in the tray (*K*). (e) After procuring the pellet, *S* could turn around in the compartment (*J*) and repeat this sequence of responses at its own rate. The exit door (*H*) was closed only at the end of the testing session.

The front and side walls of the apparatus were of wood, 21 in. high. The rear wall, a Masonite panel of the same height, contained the clear plastic response panel (*E'*) inset at the floor of the cage at (*E*). The response slot (*M*), with markings 1 cm. apart painted in black on the outside surface of the plastic, ran parallel to the floor at convenient head-height for the *S*—2 in. from the lower edge of the slot to the floor. The slot was $\frac{3}{8}$ in. wide on the outside and was beveled to a 1 in. width on the inside of the cage.

In the determination of both the length and the position of the response slot (*M*) in the apparatus, account was taken of the fact that the difference limen for the discrimination of distance in the white rat is about $\frac{1}{10}$ (**1**, **13**). The distance from the exit (*H*) to the center of the response slot (30.5 cm.) was designed to be discriminably shorter than the distance from the exit to either extreme of the slot (39.4 cm.). As a result, when the *S*s were required during conditioning to run from the compartment (*J*) to the slot (*M*) and back to the compartment (*J*) to procure reinforcement, they developed tendencies to respond about the center of the response slot. This then allowed observation of the scattering of responses around individual central tendencies and permitted application of a conventional measure of variability to distributions of response positions.

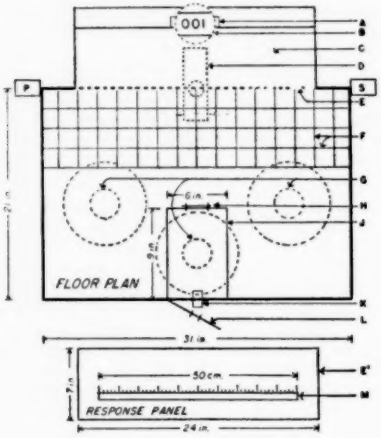

FIG. 1. Floor plan of the apparatus and diagram of the response panel. *A*—electric counter; *B*—magnifying lens; *C*—plate-glass mirror at 45° angle to base of cage; *D*—outline of 16-mm. camera position 4 ft. above cage floor; *E*—position (dashed line) of response panel; *E'*—detail drawing of response panel; *F*—white grid lines painted on black floor of cage; *G*—outlines of positions of three 75-w. lamps over cage; *H*—vertical sliding door before exit from starting-feeding compartment; *J*—starting-feeding compartment; *K*—position of feeding tray; *L*—plastic door hinged to front of cage before entrance to starting-feeding compartment; *M*—response slot with centimeter scale markings; *S*—spotlight; *P*—photoelectric cell.

The starting-feeding compartment (*J*) was of the same height as the main cage. The front panel and vertical sliding door (*H*) were of clear plastic, the sliding door covering an exit hole $2\frac{1}{4}$ in. wide and 3 in. high in the center of the front panel at the floor. The outside entrance to the compartment (*J*) was covered by a hinged, 6 in. square door of clear plastic. This door had a small slot in its center base to allow insertion and removal of a shallow, 1 in. square feeding tray (*K*) when the door was closed.

A small 10 v. AC spotlight projector (*S*) on the right side of the cage passed a narrow beam of red light behind the response slot to a photoelectric cell (*P*). The cell was calibrated to react when a strip of cardboard $\frac{1}{8}$ in. wide was inserted in the slot between $\frac{1}{4}$ and $\frac{3}{16}$ in.

By means of a mirror (*C*) placed at an angle of 45° to the base of the rear panel of the cage, and a magnifying lens (*B*) over the Veeder-Root counter (*A*), the photograph of the slot recorded the position of the rat's nose at the moment a response was made, and also the serial number of the response. Light for the photograph was provided by three 75-w. lamps in opaque reflectors (*G*). A Bolex 16 mm. motion picture camera (*D*), suspended from a boom 4 ft. above the cage floor, was used with film having a Weston rating of 100. The cage floor-temperature increased 2° to 3° within 45 min. after these lights were turned on, but room temperature remained between 68° and 74° F. throughout the experiment.

A waxed-tape, constant speed recorder (**3**) was used to record (a) the time *S* left the starting-feeding compartment and returned to it, and (b) the time of each nose response at the slot. The waxed tape was later matched exactly with the film record.

During the experiment *S*s were housed in the experimental room in individual cages (**3**). The *S*s were fed 1 hr. each day in these cages under a floor illumination (35 ft. candles) which corresponded to that prevailing in the starting-feeding

compartment (*J*) of the experimental cage. When *Ss* were not being fed, the maximum floor illumination inside their home cages was less than .5 ft. candle during daylight hours. An electric fan in one corner of the room served as a sound screen during the experiment.

The food pellets were of compressed Purina Chow, cylindrical in shape, weighing .1 ± .01 gm. As described in the procedure below, during preliminary training, conditioning, and reconditioning sessions of the experiment these pellets were fed one at a time to the *S* by means of the feeding tray (*K*). The food provided in home cages at regular feeding times consisted of ground Purina Chow and pellets. Water was available at all times in home cages, but was not available in the experimental cage.

Procedure

The procedure for the experimental *Ss* will be described in detail since the procedure for both experimental and control *Ss* was the same except that the control *Ss* did not undergo the four extinction days indicated below. The entire experiment required 16 successive days for each *S*, whether experimental or control.

Establishing feeding rhythm (Days 1 to 3).—On Day 1 each *S* was placed in a living cage in the experimental room and fed under illumination for 1 hr., after which it was handled for a few minutes and the sawdust in the cage was changed. Thereafter, throughout the experiment 23 hr. elapsed between feedings in the home cages, and the procedure on Day 1 was replicated as exactly as possible.

Operant level determinations (Day 4).—Each *S*, with its head facing the open exit (*H*), was placed in the starting-feeding compartment (*J*) of the apparatus, 75 min. before its usual feeding period. A record of its unconditioned activity was obtained for 1 hr. The method of placing the *S* in the compartment insured its soon leaving the compartment to explore the larger interior of the cage where it could find the slot in the response panel and, perhaps, thrust its nose into it thereby taking its own picture each time. Since the exit (*H*) was always kept open, *S* had free access to the entire interior of the experimental cage during the hour. The large extent and convenient height of the response slot insured its being found several times by all *Ss* during the course of the hour; similarity of the starting-feeding compartment (*J*) in dimensions and illumination level to the home cage during regular feeding hours was probably the factor which induced the deprived *Ss* to return to this compartment frequently during the hour. Each *S* was fed and handled as described above 15 min. after being returned to its home cage. The experimental cage was swabbed out and the photocell was calibrated between each *S*. Throughout the remainder of the experiment, *S* had been deprived of food for 21 hr. and 45 min. when placed in the apparatus.

Preliminary training (Day 5).—Each *S* was fed 50 food pellets accompanied by the "click" normally produced by a nose-thrusting response. The food was given in the starting-feeding compartment (*J*) at irregular intervals of 10 to 30 sec. between pellets. The exit door (*H*) was kept closed.

Conditioning Days 1 to 5 (Days 6 to 10).—On the first day of conditioning, 25 complete chains of responses were reinforced in all but three *Ss* in the total group. Each chain of responses consisted of (a) leaving the starting-feeding compartment, (b) making a recorded nose-thrusting response one or more times, and (c) returning to the starting-feeding compartment. Reinforcement (a single food pellet) was given in the starting-feeding compartment upon completion of the third element in this chain. Of the three failing *Ss*, two were in the experimental group and one was in the control group. In these cases, additional complete response chains were reinforced on the second day of conditioning to make up the differences. All *Ss* were allowed to establish their own rates of responding during conditioning.

On each of Days 2 through 5 of conditioning, 50 complete response chains were reinforced in all *Ss*. Thus, all *Ss* received 225 reinforced trials spread over five successive days. After each conditioning session, *S* was fed for 1 hr. as usual.

Extinction Days 1 and 2 (Days 11 and 12).—At the usual testing times, the experimental *Ss* were placed in the apparatus for 1 hr., but response chains were not rewarded. Control *Ss* were not extinguished but were simply fed in their home cages as usual.

Reconditioning Day 1 (Day 13).—Both experimental and control *Ss* were given 50 reinforcements of complete response chains.

Extinction Days 3 and 4 (Days 14 and 15).—The procedure was as described for Extinction Days 1 and 2.

Reconditioning Day 2 (Day 16).—The procedure was as described for Reconditioning Day 1.

Scoring of Records

The resulting 6,600 photographs of nose-thrusting responses were enlarged and the position of the nose with reference to the horizontal dimension of the response slot was measured. As seen in Fig. 1, 50 positions were marked along the slot, each separation between positions representing 1 cm. along the slot. In those in-

stances where the center of *S*'s nose appeared to coincide with a mark on the response slot, the position assigned during scoring was alternated to the right and left of the mark. All nose-thrusts were recorded, even though several sometimes occurred in a single behavior chain. The polygraph records showed that nose-thrusting responses occurred in "bursts" most frequently during the operant level determinations and the extinction sessions, but even late in conditioning *Ss* would occasionally interrupt the beam more than once before returning to the starting-feeding compartment.

Results [3]

Frequency of responding.—Table I presents the mean number of nose-thrusting reponses, regardless of position of occurrence, in each experimental phase. None of the differences between the means of experimental and control groups in any experimental phase is statistically significant.

The high frequency of responses during operant level determinations reflects the tendency of all *Ss* to respond in "bursts" during this initial session. Upon finding the response slot from time to time during the hour, the *S* was frequently observed to run back and forth from one extreme of the slot to the other with its nose sliding along in the slot; this behavior sometimes resulted in several interruptions of the light beam at random positions along the slot. Upon reaching an end of the slot, *S* often made several nose-thrusts which were recorded as separate responses. The continued appearance of these forms of behavior during the early trials of the first conditioning session accounts for the large excess of responses over the minimum expected number (25) in the first conditioning session. The excesses over 50 nose-thrusting responses in all other conditioning and reconditioning sessions represent the mean numbers of repeated or "extra" nose responses within the complete response chains which were conditioned.

For the experimental group, the high mean frequency of nose-thrusting responses in the first extinction session is the result both of the strengthening of the complete response chain by conditioning and of the occurrence of "bursts" of nose-thrusting responses within complete response chains, the "bursts" arising from behavior similar to that observed during operant level determinations. Even though mean frequencies of nose-thrusting responses on extinction days 2, 3 and 4 are below the operant level mean frequency for the experimental

TABLE I

Mean Number of Nose-Thrusting Responses in Each Phase of the Experiment

Experimental Phase	Group		
	Exper. (N =6)	Control (N =6)	Total (N =12)
Operant level	60.2	51.8	56.0
Conditioning 1*	43.8	65.8	56.0
Conditioning 2*	58.8	63.4	61.3
Conditioning 3	62.0	64.0	63.0
Conditioning 4	62.0	66.2	64.1
Conditioning 5	58.7	66.7	62.7
Extinction 1	107.8		
Extinction 2	48.8		
Reconditioning 1	59.3	69.5	
Extinction 3	54.5		
Extinction 4	39.8		
Reconditioning 2	56.5	65.7	

* For reasons noted in the text, in Conditioning 1 and 2 only 4 *Ss* are represented in experimental group means, 5 *Ss* in control group means, and 9 *Ss* in total group means.

[3] Complete tabulations of original data from which this summary has been drawn will be found in the original report of this research available on microfilm under the title "Variability of Response in the White Rat during Conditioning and Succeeding Extinction and Reconditioning" from University Microfilms, Ann Arbor, Michigan. The original report contains analyses of other variable aspects of the behavior of the white rat in the situation employed.

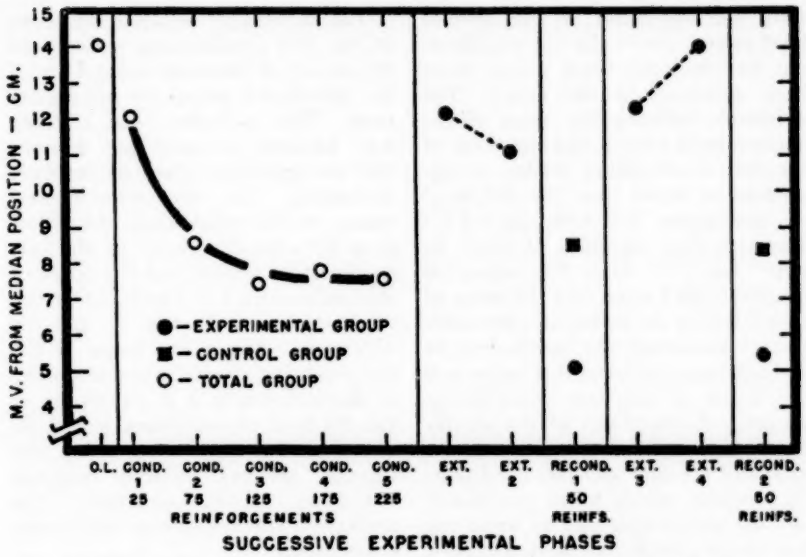

FIG. 2. Response variability during operant level determinations, conditioning, extinction, and reconditioning. (N = 12 through Conditioning 5, N = 6 for each point thereafter.)

group, the strength of the complete response chain is above the operant level strength in all instances. The mean frequencies of complete response chains on extinction Days 1 through 4 were, respectively: 40.5, 20.5, 26.3, and 15.2. The operant level mean frequency of complete response chains for the experimental group was 9.5 (for the total group, 9.6). Using the correlated variables formula for t (7, p. 59), the differences between the mean operant level frequency of complete response chains and the means of the four extinction sessions are all significant at the .05 level or better for the experimental group.

Variability between sessions.—Frequency distributions of response positions were prepared for individual Ss by testing sessions. Many of the distributions thus obtained were skewed and departed in other ways from normality, particularly for the operant level determinations and extinction sessions where the distributions were markedly platykurtic in comparison with the approximately normal distributions for conditioning sessions. In view of this, the median was chosen in preference to the mean as the measure of central tendency from which mean variations were computed as measures of response variability.

The means of the mean variations from the median nose position are plotted in Fig. 2 for each phase of the experiment.[4] The differences between means of mean variations of the experimental and control groups

[4] In Fig. 2, the means of mean variations for Conditioning 1 and 2 do not include the data of the three Ss previously noted as having failed to emit the requisite number of complete response chains on the first day of conditioning and having received additional reinforcements to make up differences on the second conditioning day.

were not significant in the operant level session nor in the five conditioning sessions, and these groups have been combined in the figure. The difference between the mean of the operant level session and the mean of the last conditioning session is significant at better than the .001 level of confidence ($t = 6.04$, $df = 11$).[5] The fact that the data of three *Ss* were discarded from the mean of Conditioning 1 (and also the mean of Conditioning 2) makes it impossible to test accurately the significance of the difference between this mean and the mean of the last conditioning session. A crude test of the significance of the difference between the means of the first and last conditioning sessions which takes correlation into account is obtained by using the data of the nine *Ss* represented in both sessions. This test indicates that the difference between the means of these sessions is significant at the .05 level ($t = 2.82$, $df = 8$). The course of the curve during conditioning indicates that response variability is a decreasing monotonic function of number of reinforcements. A stable level of response variability appears to be reached on the third day of conditioning—between 75 and 125 reinforcements.

The differences between the mean of the last conditioning session and the means of Reconditioning 1 and 2 for the control group are not significant. This indicates that a 2-day rest between conditioning sessions had no significant effect on response variability. In the experimental group, on the other hand, the difference between the mean of the last conditioning session and the mean of Reconditioning 1 is significant at the .01 level ($t = 6.53$, $df = 5$), and the difference between the mean of the last conditioning session and the mean of Reconditioning 2 is significant at the .05 level of confidence ($t = 2.90$, $df = 5$). The two intervening extinction sessions reduced response variability significantly below the asymptote reached during continuous conditioning.

In the experimental group, the increase in response variability from Conditioning 5 to Extinction 1 is significant at the .02 level ($t = 3.69$, $df = 5$), and the increase from Reconditioning 1 to Extinction 3 is significant at the .01 level ($t = 4.80$, $df = 5$). The slight changes in mean variability between Extinction 1 and 2, and between Extinction 3 and 4 are not significant. The decrease in mean variability from Extinction 2 to Reconditioning 1 is significant at the .01 level ($t = 5.56$, $df = 5$), and the decrease from Extinction 4 to Reconditioning 2 is significant at the .001 level ($t = 8.89$, $df = 5$).

Variability within sessions.—To obtain information concerning the changes in response variability during the conditioning sessions, the positions of nose-thrusting responses were tabulated for successive fifths of the reinforcements in each session. Medians and mean variations from medians were computed for each of the five distributions for each *S* in each

The reason for the exclusion of the three failing *Ss* was the finding of the marked within-session change in variability shown in Fig. 3, which meant that a plot of variability vs. reinforcements without regard to session of occurrence of the responses involved would not be accurate. In view of the fact that the distributions of response positions for the three failing *Ss* were not based on the same numbers of reinforcements within these two sessions as the distributions of the majority of the *Ss*, inclusion of their data would have resulted in a slight distortion of the mean values yielded by 9 *Ss* under uniform conditions.

[5] The correlated variables formula for t (7, p. 59) was used here and in all subsequent tests of the significance of the difference between correlated means in this report.

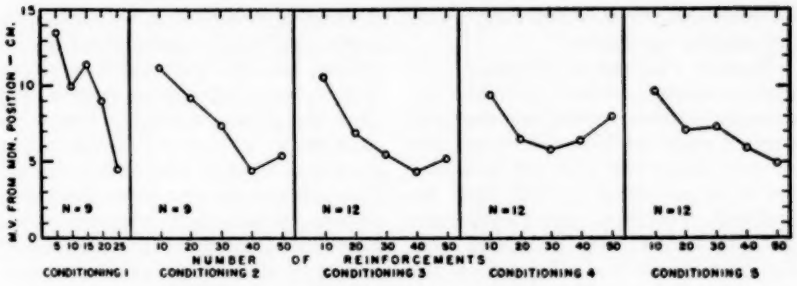

FIG. 3. Response variability within conditioning sessions

session. A plot of the means of these measures of response variability during the five conditioning sessions is shown in Fig. 3; a similar plot of response variability during the two reconditioning sessions is given in Fig. 4. Clearly, response variability decreases during each conditioning session and increases, although perhaps without complete recovery, from the end of one session to the beginning of the next. The differences between the initial and final points within each session are significant at better than the .05 level, except in Conditioning 4. The differences between the final point of one session and the initial point of the next are significant at better than the .05 level, except between Conditioning 4 and 5. The decrease in initial variability from Conditioning 1 to Conditioning 5 is significant at the .02 level. (In order to take correlation into account, the tests of the significance of the difference between the final point of Conditioning 2 and the initial point of Conditioning 3, and between the initial points of Conditioning 1 and 5 employed the data of only 9 *Ss* represented in both sessions.) Comparison of the curves for experimental and control groups in Fig. 4 suggests that late in the reconditioning sessions the prior extinction exercises a stronger stereotyping influence on the position

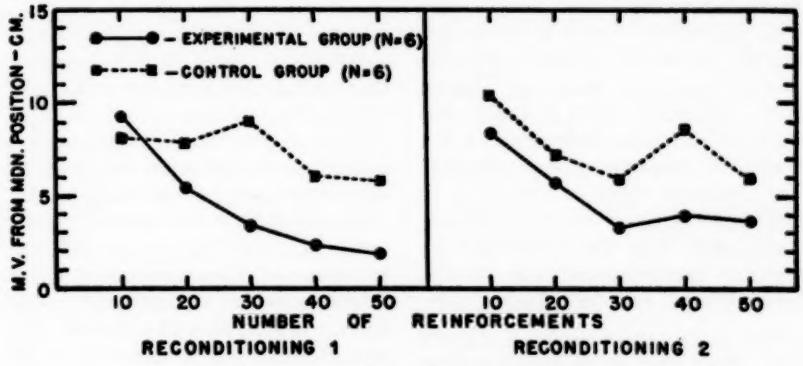

FIG. 4. Response variability within reconditioning sessions

of responding than it does early in the reconditioning sessions.

Similar analyses of response variability during operant level and extinction sessions could not be performed since the base line of number of reinforcements was not available for dividing responses and their respective positions into equivalent groups within those sessions. No satisfactory method of treating the data so as to reveal average trends of response variability within those sessions could be worked out. A crude analysis of changes in the variability of responding of individual *Ss* was performed by taking responses in groups of ten from start to finish of operant level and extinction sessions and computing mean variations from median positions for successive groups.[6] Inspection of the results revealed that response variability, while generally high in comparison with variability during conditioning, followed no regular trend during operant level determinations or extinction sessions.

Discussion

The decrease in response variability with reinforcement confirms previous findings and observations of Muenzinger (**8**) and Skinner (**10**). The increase in response variability during extinction is consistent with the implication of studies by Skinner (**10**) and others (**4, 5, 6, 9, 11**) that extinction induces an increase in the range of response forms emitted. The practical value of extinction in making available novel response forms which may then be conditioned by selective reinforcement has already been pointed out by Skinner (**10**).

[6] The results obtained are given in Table IX of the original report of this research available from the source indicated in footnote 3.

The novel finding that extinction following extended regular conditioning affects response variability in subsequent reconditioning in such a way that variability is reduced below the asymptote of regular conditioning does not appear predictable on the basis of any current theoretical construct. While such a result would have been expected had some form of discrimination training been employed, the relation of the present procedure to the usual discrimination training procedure is not clear.

The decrease in variability during conditioning and reconditioning sessions confirms and amplifies a similar finding by Wingfield and Dennis (**12**) in a situation in which the *Ss* were given two equally attractive modes of responding. This decrease in variability cannot, however, be considered to be a simple function of number of reinforcements. At least one other variable, degree of food-deprivation, is also being modified by continuous ingestion of food pellets during training sessions. The present results provide no indication of what change in response variability would occur if feeding of *Ss* were carried to the point of satiation in conditioning sessions. An earlier study by Elliott (**2**) of variability in the locus of the rat's response in a situation offering five equal-length paths to food suggests that variability increases at or near the point of satiation.

With respect to variability during operant level and extinction sessions, while the present results suggest that it remains high and follows no regular trend in these sessions, a different technique of experimentation which would provide a satisfactory base line for the division of responses into equivalent groups is necessary to obtain a clear picture of average results.

Summary and Conclusions

The variability of nose-thrusting responses of 12 male albino rats was determined during unconditioned responding, extended regular conditioning, extinction, and reconditioning under conditions which required each rat to run from a starting-feeding compartment to a 50 cm. response slot, insert the nose in the slot, and return to the compartment. Variability of nose position was determined for each rat in terms of the mean variation of the response from the median position.

The results led to the following conclusions:

1. Response variability is a decreasing monotonic function of the number of reinforcements when given in blocks in successive conditioning sessions. An asymptote was determined within the 225 reinforcements involved in the experiment.

2. Variability is consistently greater at the beginning than at the end of conditioning and reconditioning sessions.

3. Reconditioning after extinction leads to lesser response variability than at any time during continuous conditioning. This effect is not enhanced by further extinction and reconditioning. The decrease in variability produced by prior extinction occurs late rather than early in reconditioning sessions.

4. During unconditioned responding and extinction periods, records of individual *Ss* indicate that variability is relatively high and follows no regular trend in contrast with variability during conditioning and reconditioning.

(Manuscript received
November 28, 1950)

References

1. DeCamp, J. E. Relative distance as a factor in the white rat's selection of a path. *Psychobiology*, 1920, **2**, 245–253.
2. Elliott, M. H. The effect of hunger on variability of performance. *Amer. J. Psychol.*, 1934, **46**, 107–112.
3. Frick, F. C., Schoenfeld, W. N., and Keller, F. S. Apparatus designed for introductory psychology at Columbia College. *Amer. J. Psychol.*, 1948, **61**, 409–414.
4. Gengerelli, J. A. Preliminary experiments on the causal factors in learning. *J. comp. Psychol.*, 1928, **8**, 435–457.
5. Guthrie, E. R., and Horton, G. P. *Cats in a puzzle box.* New York: Rinehart, 1946.
6. Kuo, Z. Y. The nature of unsuccessful acts and their order of elimination in animal learning. *J. comp. Psychol.*, 1922, **2**, 1–27.
7. Lindquist, E. F. *Statistical analysis in educational research.* Boston: Houghton Mifflin, 1940.
8. Muenzinger, K. F. Plasticity and mechanization of the problem box habit in guinea pigs. *J. comp. Psychol.*, 1928, **8**, 45–70.
9. Sharp, W. L. Disintegrative effects of continuous running and removal of the food incentive upon a maze habit of albino rats. *J. comp. Psychol.*, 1929, **9**, 405–423.
10. Skinner, B. F. *The behavior of organisms.* New York: D. Appleton-Century, 1938.
11. Warden, C. J., and Lubow, L. Effect of performance without reward on the retention of the maze habit in the white rat. *J. genet. Psychol.*, 1942, **60**, 321–328.
12. Wingfield, R. C., and Dennis, W. The dependence of the rat's choice of pathways upon the length of the daily trial series. *J. comp. Psychol.*, 1934, **18**, 135–145.
13. Yoshioka, J. G. Weber's law in the discrimination of maze distance by the white rat. *Univ. Calif. Publ. Psychol.*, 1930, **4**, 155–184.

EARLY PUBLICATION

IN

APA JOURNALS

The policy of accepting articles for immediate publication (providing the editor accepts the article and the author is willing to pay the entire cost of increasing the next available issue by enough pages to add his article to the normal content) is now standard practice for all APA journals except *Psychological Abstracts* and the *American Psychologist.*

The actual charge made to the author includes three items:

1. A basic charge of so much per page. This is the minimum amount that it costs to add an additional page to the journal. For 1951 these costs are:

	Per Page
Journal of Abnormal and Social Psychology	$17.00
Journal of Consulting Psychology	14.00
Journal of Comparative and Physiological Psychology	11.00
Journal of Consulting Psychology	14.00
Journal of Experimental Psychology	14.00
Psychological Bulletin	17.00
Psychological Monographs: General and Applied	15.00*
Psychological Review	14.00

* Since each Psychological Monograph is printed separately, the author of one handled on an early publication basis can be charged exactly the cost of printing. The figure of $15.00 is an approximate one; the actual figure will be higher for very short monographs and lower for very long ones. The cost will also vary depending upon the amount of special composition and the illustrations used.

These charges are based upon several factors:

(a) The greater number of words on a particular journal page, the higher the cost per page. Conversely, the fewer words printed on the page, the lower the cost per page.

(b) The more copies which must be printed, the higher the cost.

(c) The more expensive the printer, the higher the cost. Compared to the factors listed above, this is not an important difference in the charges made.

2. The full cost of any cuts or other illustrative material, of special composition for tables, and of author's changes in proof.

3. The full cost of any reprints ordered. (Authors of early-publication articles do not receive any free reprints.)

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

The issues listed below are available for sale

Year	Volume	Available Numbers						Price per Number	Price per Volume
1916	1	1	2	3	4	5	6	$1.25	$7.00
1917	2	1	2	–	4	5	–	$1.25	$5.00
1920	3	–	2	3	4	5	6	$1.25	$6.25
1921	4	1	2	3	4	5	6	$1.25	$7.00
1922	5	–	–	3	4	5	6	$1.25	$5.00
1923	6	–	–	–	–	–	–	——	——
1924	7	1	2	–	–	5	–	$1.25	$3.75
1925	8	1	2	3	4	–	6	$1.25	$6.25
1926	9	–	2	3	–	5	6	$1.25	$5.00
1927	10	–	–	3	4	5	6	$1.25	$5.00
1928	11	1	2	3	4	5	6	$1.25	$7.00
1929	12	1	2	3	4	5	6	$1.25	$7.00
1930	13	1	2	3	4	5	6	$1.25	$7.00
1931	14	1	2	3	4	5	6	$1.25	$7.00
1932	15	1	2	3	4	5	6	$1.25	$7.00
1933	16	1	2	3	4	5	6	$1.25	$7.00
1934	17	1	2	3	4	5	6	$1.25	$7.00
1935	18	1	2	3	4	5	6	$1.25	$7.00
1936	19	1	2	3	4	5	6	$1.25	$7.00
1937	20	1	2	3	4	5	6	$1.25	$7.00
	21	1	2	3	4	5	6	$1.25	$7.00
1938	22	1	2	3	4	5	6	$1.25	$7.00
	23	1	2	3	4	5	6	$1.25	$7.00
1939	24	1	2	3	4	5	6	$1.25	$7.00
	25	1	2	3	4	5	6	$1.25	$7.00
1940	26	1	2	3	4	5	6	$1.25	$7.00
	27	1	2	3	4	5	6	$1.25	$7.00
1941	28	1	2	3	4	5	6	$1.25	$7.00
	29	1	2	3	4	5	6	$1.25	$7.00
1942	30	1	2	3	4	5	6	$1.25	$7.00
	31	1	2	3	4	5	6	$1.25	$7.00
1943	32	1	2	3	4	5	6	$1.25	$7.00
	33	1	2	3	4	5	6	$1.25	$7.00
1944	34	1	2	3	4	5	6	$1.25	$7.00
1945	35	1	2	3	4	5	6	$1.25	$7.00
1946	36	1	2	3	4	5	6	$1.25	$7.00
1947	37	1	2	3	4	5	6	$1.25	$7.00
1948	38	1	2	3	4	5	6	$1.25	$7.00
1949	39	1	2	3	4	5	6	$1.25	$7.00
1950	40	1	2	3	4	5	6	$1.25	$7.00
1951	41								
	42	By subscription, $14.00 (2 vols.)						$1.25	——
		List price, Volumes 1 through 40							$260.25
		30% discount							78.08
		Net price, Volumes 1 through 40							$182.17

Information about the Journal of Experimental Psychology: as noted in the table, the journal was not published in 1918 and 1919; from 1937 to 1943 it was published at the rate of two volumes per year; from 1944 to 1950, in one volume per year. Beginning in 1951 there are two volumes a year.

Information about prices: when all numbers are available, the price per volume throughout the series is $7.00. For incomplete volumes, the price is $1.25 for each available number. For foreign postage, $.25 per volume should be added. The American Psychological Association gives the following discounts on orders for any one journal:

10% on orders of $ 50.00 and over
20% on orders of $100.00 and over
30% on orders of $150.00 and over

Address orders and subscriptions to

AMERICAN PSYCHOLOGICAL ASSOCIATION

1515 Massachusetts Avenue N.W. Washington 5, D. C.